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NIGHTTIME CONSTRUCTION IMPACTS ON SAFETY, QUALITY, AND PRODUCTIVITY

FINAL REPORT

Prepared for the
National Cooperative Highway Research Program
Transportation Research Board
of
The National Academies

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DISCLAIMER

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ABSTRACT

Nighttime construction and maintenance activities are becoming more predominant in the transportation agencies across the United States. Concern over the impact of nighttime activities on risk, illumination, nuisances, productivity, quality, cost, safety, and communications, compared to daytime activities, has inhibited its use by some agencies.

Through a multi-method approach of literature, survey, case studies (with semi-structured interviews), and field data collection, the discrepancies between nighttime and daytime activities were found to be minimal. With early identification of issues and good planning, beginning in early project development, the advantages of nighttime construction can outweigh the difficulties and yield a successful project.

EXECUTIVE SUMMARY

Roadways in the United States are becoming more congested each day. These same roads are also often reaching the middle or end of their useful lives. Transportation agencies are working hard to meet the demands of the traveling public through construction and maintenance activities. Because of increased traffic congestion during the day, road construction and maintenance activities are being conducted during nighttime hours. However, concerns have been expressed about the impact of nighttime activities on risk, illumination, nuisances, productivity, quality, cost, safety, and communications. These concerns have prompted research investigating the impacts and the development of a practice-oriented guidebook for nighttime construction and this research report.

Through a multi-method approach, including literature, surveys, case studies using semi-structured interviews, and field data collection in a number of states, several conclusions have been reached:

- Successful nighttime construction requires good illumination.
- The decision to use nighttime construction should be made as early in the project development process as possible.
- The areas of nighttime construction concern are not mutually exclusive, as there is interaction (added cost for illumination and better traffic control but productivity is usually better; therefore, overall project cost is comparable to cost for a daytime project).
- Early decision making and proper planning can limit the disadvantages of nighttime work and enhance the advantages.

CHAPTER 1: BACKGROUND

1.1 Introduction

Traffic congestion, especially in metropolitan areas, places a significant and serious burden on the public and threatens the economic vitality of the nation. A significant portion of traffic congestion is attributable to roadway construction and maintenance activities (10 to 24 percent reported in various studies). One way to reduce the congestion effects of roadwork activities is to perform them during times of reduced traffic demand.

Traffic demand fluctuates dramatically over the 24 hour period, with the percentage of daily traffic that occurs each hour much less during the evening and early morning hours than it is during the daytime. Data taken during the summer of 2001 suggests that a third of the work zones present on national highway system roadways were active primarily at night, compared to 58 percent of the work zones that were active during the day, and that nine percent of the projects involved continuous work activities over both daytime and nighttime hours (Ullman 2004).

1.2 The Problem

Although the benefits to performing work activities at night are obvious and significant (particularly on high-volume roadways where any traffic-flow restrictions during the day can create serious congestion and delay), a number of issues can make night work a challenge.

Safety of Personnel: Depending on the sources cited, night work presents challenges to the highway work crews. For example, night work generally involves somewhat degraded vision for the workers due to lower overall luminance levels in the work zone at night compared to daytime work operations, the effects of shadows created by equipment and materials, and glare from vehicle headlights and equipment lights around the work area. In addition, concerns exist over potential degradations in worker levels of attention and overall health, due to the ongoing disruption of the natural circadian rhythms of the human body. Finally, questions have arisen as to the effect of performing roadwork at night, specifically as it affects worker quality of life with reduced social- and family-interaction opportunities.

Safety of Traveling Public: The challenging issues related to the driving public that are most commonly cited include: reduced visibility for drivers due to lower levels of light available at night (this is especially an issue for older drivers with vision deterioration); decreased driver expectancy for encountering road work activities at night; higher percentages of impaired and/or drowsy drivers on the road at night; and higher traffic speeds approaching and traveling through the work area (potentially leading to more severe crashes if they occur).

Quality of Work and Production: Working at night can have implications on work quality, production rates, and costs, which translate into higher cost for the agency. The effects of lower light levels on worker vision may reduce work quality, and night work typically requires a cost premium for materials and labor. However, lower traffic volumes may make it easier and quicker for materials to be delivered to the job site or transported from the site, potentially increasing productivity and reducing overall construction costs.

Construction Nuisances: Night work can have impacts, on adjacent neighborhoods and businesses that would not be experienced or as disturbing if conducted during the daytime. These impacts include noise levels that affect sleep patterns of nearby residents, glare from temporary lighting systems intruding on residential dwellings, and accessibility to businesses that operate primarily at night.

The hazards, demands, and nuisances have been the subject of a number of previous research studies:

- Illumination requirements of nighttime work zones (El-Rayes and Hyari 2005a, El-Rayes and Hyari 2005b, Hyari and El-Rayes 2006a, Hyari and El-Rayes 2006b, Nassar 2008)
- Evaluation of construction nuisances during nighttime work zones (Schexnayder 1999, Schexnayder and Ernzen 1999)
- Evaluation of the impact of nighttime work zones on driver and worker safety (Arditi et al. 2004, Arditi et al. 2007)
- Quantification of the impact of nighttime operations on construction cost and quality (Lee and Thomas 2007, Al-Kaisy and Nassar 2005, Kumar and Ellis 1994)

While these studies have made significant contributions to the advancement of the practice of nighttime construction, a comprehensive guideline for nighttime construction work in transportation corridors does not exist.

During previous research by our team, 27 state transportation agencies (STAs) reported that they have experienced serious nighttime construction issues (Schexnayder and Ernzen 1999). From conversations with agencies, project specifications can be used to create a viable nighttime construction environment.

Controlling specifications clearly indicate to the contractor the critical issues and how they must be addressed. A good construction specification is an effective tool in mitigating the effect of nighttime construction issues. The mechanisms to achieve that goal vary from contract to contract, because of area-specific conditions, the type of construction, the traffic flow that must be handled, the inherent nature of project neighbors, and the desires of the community.

Supplemental standard provisions can dictate specific measures on a contract-by-contract basis to address special local issues. The existence and importance of nuisance control specifications should be emphasized at pre-bid and pre-construction conferences.

During this initial phase of the research, transportation-agency specifications relating to nighttime work were collected and cataloged for use in developing the Guidebook for this project.

1.3 The Research Project

The main objective of this project is to develop comprehensive guidelines for the conduct of nighttime highway construction and maintenance operations. Two products were produced by the project:

- Final report that documents how the research was conducted
- Guidebook that transportation agencies can use in planning and conducting nighttime construction projects

1.3.1 Phase I

The Phase I report summarized the information gathered during Tasks 1 and 2, provided more information on Phase II, and presented a draft outline for the Guidebook. The Task 1 Literature Review involved the collection and synthesis of published information relating to experiences and studies concerning nighttime construction. It ascertained the extent of documented situations. During Task 2, Collect Information, the research team contacted the 50 STAs by email and phone and queried each about experiences with nighttime construction, as well as who within an agency would be the best person to interview concerning the information necessary to fulfill the research tasks.

1.3.2 Phase II

Phase II of the research focused, first, on the collection of information from transportation agencies through case studies. After that, data were collected to develop this report and the Guidebook.

1.4 Final Report Layout

The results of this research are presented in this report. The results are followed by information describing how Phase I and Phase II work were conducted. The second chapter provides a synopsis of the literature review findings, where a section on each of the topical areas is included. The third chapter details the survey methodology and findings from the first phase of the project. It includes a section on each of the topical areas of interest. The fourth chapter focuses on the data collection. Chapter 5 explains the development of the Guidebook. This chapter does not provide the information that is in the Guidebook: it provides the development approach. The final chapter focuses on the conclusions of the research and the practice-oriented, application-based conclusions that are presented in the Guidebook.

CHAPTER 2: LITERATURE REVIEW

The literature review involved researching, gathering, reading, note taking, and processing published information relevant to the research. Two methodologies were used to identify information. The first method sought to identify sources through a number of search techniques and explorations using keywords that identified areas of significance to the research. The following search engines were used:

- The general Internet, using Yahoo and Google
- Transportation Research Information Services (TRIS)
- Academic resources
- Research institutions, such as the Construction Industry Institute (CII) and Transportation Research Board (TRB)
- Societies for journal and conference publications, consisting of the American Society of Civil Engineers (ASCE) and the Association for the Advancement of Cost Engineering (AACE International)
- Government publications, both federal and state, United States General Accounting Office, and STA research departments

Efforts were made to gather the literature of interest using the internet search engines, as well as through visits to various libraries and through interlibrary loan services and document request functions. Some representative search terms include:

- Nighttime construction
- Productivity
- Quality
- Risk
- Safety
- Illumination
- Nuisances
- Cost estimation
- Communications

Searches were made with each of these words individually and jointly and with more specific terms, such as highway, transportation, infrastructure, and construction.

The second method for seeking possible literature of interest was through the references noted in the examined literature. Each document gathered was read and notes taken on information relevant to the research. Some sources of information were summaries of a number of previous research efforts. In cases like this, the original sources were sought, rather than relying on the summaries. The notes about sources and source information were then filtered, and pertinent information was thereby extruded.

Both general and nighttime-specific information was collected and explored. All of the pertinent information is provided in the literature review. Each discussion of the specific topical area includes the problems, study methods, and approaches of each area. Tables of identified literature are provided in this chapter.

2.1 Quality Impacts of Nighttime Construction

Construction quality during nighttime work is a concern of many transportation agencies. Quality problems have been documented in the literature. In addition, a number of studies conducted on construction quality present approaches for improving quality. However, none were found that specifically suggested approaches for improving quality at night.

2.1.1 Problems

Working at night can have implications on the quality of the work. The effects of lower light levels on worker vision can contribute to reduced work quality. Different types of work are more suitable for nighttime construction and are not inhibited by the time of day, the way other work may be affected. Table 2.1 indicates the suitability of various construction activities to nighttime work (Al-Kaisy and Nassar 2005). This was achieved by conducting a survey requesting people to comment on the suitability of the task. A higher suitability corresponds to a higher rank, indicating more suitability for nighttime work. The top-ranked activities involve work on concrete pavement and concrete sawing.

In addition, the quality of construction work is related to the ability of project staff to perform necessary inspections (inspectabililty). Table 2.2 shows the visual requirements for performing pavement marking activities (Hyari and El-Rayes 2006b). These visual requirements determine the inspectability of different types of work. This begins by looking at the visual acuity or the capacity of humans to identify standard targets at a fixed distance and contrast between the target and the background in different levels of lighting.

The first column ($VA_{required}$) reports on the acuity needed to see for the activity. The second column ($VA_{comfort}$) reports the level needed for comfortable viewing of the target. Finally, the last column shows the level of illumination needed to complete the activity. A higher number indicates a greater amount of lighting needed. The most demanding type of work in terms of the need for light is a series of painted lines on the pavement surface (pavement stripes), given it requires the highest visual requirements compared too many other activities. The visual requirements for inspectability purposes are dependent on the type of construction work.

Table 2.1. Ranking of suitability of construction work for nighttime construction (Al-Kaisy and Nassar 2005)

	State Agencies		Illinois DOT Districts			State Agencies		Illinois DOT Districts	
Construction Activities	**Average**	**Rank**	**Average**	**Rank**	**Maintenance Activities**	**Average**	**Rank**	**Average**	**Average**
Concrete sawing	4.13	1	4.13	1	Milling and removal	4.31	1	3.88	2
Bituminous surfaces and pavements	4.00	2	4.00	2	Repair of concrete pavement	4.23	2	4.38	1
Work traffic control	3.83	3	3.80	4	Resurfacing	4.23	3	3.75	3
Bridge construction	3.82	4	3.86	3	Bridge decks rehab and maintenance	4.17	4	3.29	4
Shoulders: Bituminous and Portland cement concrete	3.67	5	3.80	5	Pot hole filling	4.08	5		5
Highway signing	3.59	6	3.57	6	Waterproofing/sealing	4.00	6	2.00	11
Pavement marking: striping and markers	3.50	7	3.47	7	Crack filling	3.73	7	2.57	9
Electrical wiring and cables	3.31	9	3.46	8	Sweeping and cleanup	3.50	8	3.14	6
Culverts and sewers	3.25	8	3.15	13	Surface treatment	3.50	9	2.50	10
Drainage structures	3.25	10	3.15	14	Reworking shoulders	3.00	10	2.83	7
Sub-base and base course	3.19	11	3.38	9	Maintenance of earthwork/embankment	2.55	11	1.20	12
Concrete pavements and sidewalls	3.18	12	3.21	11	Drainage structures maintenance and rehabilitation	2.50	12	2.67	8
Electrical poles/ lighting/traffic signals	3.12	13	3.21	12	Sidewalks repair and maintenance	2.17	13	1.00	13
Subgrade	3.06	14	3.23	10					
Earthwork: excavation/ embankment/backfill	2.88	15	3.14	15					
Guardrail and fences	2.81	16	2.92	16					
Erosion control: riprap/ditch lining	2.21	17	2.27	17					
Landscaping: seeding/ mulch/sodding/planting	1.79	18	1.82	18					

Table 2.2. Visual requirements for pavement marking activities (Hyari and El-Rayes 2006b)

Task	**Worker**	**Critical Detail**	**Required Visual Acuity $VA_{required}$**	**Comfort Visual Acuity $VA_{comfort}$**	**Required Task Luminance $L_s(cd/m^2)$**
Spotting	Spotting workers	Spotting string line	0.145	0.291	0.18
Marking	Marking machine operator	Front wheel of guidance bar	0.058	0.116	0.06
		Paint spots on pavement	0.465	0.930	2.11
	Paint system operator	Nozzles of paint guns	0.174	0.349	0.15
		Paint spots on pavement	0.233	0.465	0.17

Methods for achieving better construction on quality have been studied by a number of researchers (Table 2.3). A majority of this research is recent, with the oldest being from 1991 and the most recent published since 2000. Most of the literature focuses more on the construction quality aspects in general, rather than nighttime specifically.

2.1.2 Study Methods

Several different types of methodology are used when conducting construction quality studies (Table 2.3). Field measurements are the most common approach used by researchers. Different types of field measurements include case studies, modeling, site observations, and experiments. Oztas et al. (2007) utilized case studies as the means of developing quality measurement matrices for Quality Management Systems (QMS) operating firms. Case studies were utilized by other researchers as a way of gathering in-depth information in a particular area.

Models were developed in a number of studies, such as the two-matrix models (Oztas et al. 2007), as a way to measure the effectiveness of QMS. On the other hand, prevention–appraisal–failure (PAF) modeling was chosen as a methodology to assess the quality performance of construction organization and projects by Tam and Le (2007) and Abdelsalam and Gad (2009).

Besides field measurements, interviews were frequently used in studying construction quality. Researchers favor interviews as a way to gather in-depth information on certain issues. Burati et al. (1991) conducted a series of interviews with construction, engineering, procurement, and quality personnel from various owner and contractor firms involved primarily in heavy industrial, manufacturing, and commercial construction. Sometimes, interviews were used to help in the development of questionnaires. This method was used by Al-Momani (2000), with selected survey participants, such as project owners of both private and public sectors and contractors.

Table 2.3. Quality literature

Methodology and Solutions	**Authors**													
	Burati et al. 1991	Arditi, Gunaydin 1997	Serpell 1999	Al-Momani 2000	Al-Kaisy, Nassar 2005	Hyari, El-Rayes 2006b	Lam, Ng 2006	Oztas et al. 2007	Tam, Le 2007	Leung et al. 2008	Tam et al. 2008	Wang 2008	Abdelsalam, Gad 2009	Yung, Yip 2009
Research Method														
Survey				G	N			G						
Literature review	G	G											G	
Interviews	G		G	G		N				G			G	
Framework							G							
Prototype							G							
Field measurements														
Other study				G					G					
Case study								G	G			G	G	
Simulation											G			
Modeling								G			G			G
Observation/visit			G						G					
Data set	G								G		G			G
Experiments/lab/test						N				G		G		
Solutions														
Quality management strategies/methods/ programs	G	G	G		N		G	G	G	G	G			
Development of system/design/ model/theory							G			G		G		
Quality cost					N								G	
Construction performance/ processes				G		N								G

N = Nighttime, G = General

In addition to the above methodologies, survey is another tool widely used to gather construction quality information. Both Al-Momani (2000) and Oztas et al. (2007) conducted structured questionnaire surveys of a random sample of project owners, construction personnel, and contractors from the private and public sectors.

2.1.3 Approaches

A number of researchers have explored approaches for improving quality of construction products. Studies have explored options to address both quality and inspectability issues. The most common option is appropriate quality management strategies, methods, or programs.

Quality management strategies help in achieving substantial improvements in meeting quality requirements (Burati et al. 1991). According to Burati, management participation in the implementation process is an essential ingredient for successful quality management programs. This is supported by Arditi and Gunaydin (1997) during their studies on total quality management in construction processes.

Management strategies for nighttime construction may include clear guidelines regarding increased inspectability, including illumination and testing. Management participation should come from both the agency and contractor, indicating that quality is an important aspect of construction.

Another method for improving quality in construction is by implementing a web-based quality management system (Lam and Ng 2006). This system can be an effective tool for gathering, filtering, managing, assessing, and sharing quality data. This approach should work well in the nighttime construction environment. Lam and Ng (2006) developed a prototype of Internet Facilitated Quality Management (IFQM–EQUALITY) using a bundle of software and programming, before implementing a web-based quality management system.

2.2 Safety

Because of the poor visibility commonly associated with nighttime work zones, the safety of construction personnel and the traveling public must be given much more attention when agencies plan to conduct projects that commence with the onset of dusk or later.

2.2.1 Problems

Nighttime project activities can cause significant hazards to both construction workers and the traveling public. These hazards are attributed to decreased visibility, higher vehicle speeds, and driver impairment by alcohol, drugs, fatigue, and age-related vision reduction (Arditi et al. 2004). These causes lead to higher nighttime work zone fatalities compared to daytime work-zone rates (Arditi et al. 2004).

Concerns about safety are important considerations in decisions about performing construction at night (Arditi et al. 2003). The impacts of nighttime construction on safety have been studied by a number or researchers (Table 2.4).

These studies looked at both accident causes and ways to prevent both worker accidents and the traveling public accidents within the work zone. Methods of study include analysis of crash and accident data, surveys, interviews, speed data, and field measurements.

2.2.2 Study Methods

The most utilized methodology for studying safety is surveys. This is followed by various types of field measurements, interviews, and focus groups. Surveys were used by seven of the identified research reports. Participants in the surveys included STA staff, owners, contractors, construction workers, and the traveling public. Abraham et al. (2007) utilized multiple surveys, and different forms for the various participant groups. That research work covered a broad range of topics. It differs from other research that focused on only a few particular solutions and the use of a single survey.

Different types of data have been used in the research of nighttime work-zone safety. These include LUMINA (a system developed to measure the luminance of safety vests in nighttime conditions per Arditi et al. 2004), crash data, accident data, data from observational studies, and data from on-site tests. LUMINA, which measured the luminance of personal protective equipment (PPE), involved video transformed into still-shots. The average luminance from the still-shots was calculated and indexed to determine the most-reflective PPE type.

Crash data provides information about incidents involving the traveling public. The data from various STAs were used to determine the impact of nighttime work zones on the number of incidents experienced by the traveling public. The data were collected from police, highway patrol, and STA sources. This information was also obtained for non-work-zone areas to establish a comparison of incident levels.

Accident data differs from crash data in that it does not include the traveling public. Work-zone accidents are events that occur within the construction work area. Hirasawa et al. (2007) used accident data along with surveys to determine the level of safety for various types of PPE and site characteristics for trucking contractors in nighttime construction work zones. Others researchers have used the accident data to determine if the rate of accidents on activities completed at night is different from rates for daytime work.

As a follow-on to their initial surveys, Hancher et al. (2007) used focus groups to obtain more in-depth information. Hancher et al. suggested that, by conducting focus-group meetings, they were able to learn more about the issues listed on the survey and to explore issues that were not mentioned. The additional information helped the researchers to develop the final analytical surveys.

Table 2.4. Safety literature

	Authors											
Methodology and Solutions	Arditi et al. 2003	Arditi et al. 2004	Sayer, Mefford 2004	Ullman et al. 2004	Arditi et al. 2005	Ullman et al. 2005	Hirasawa et al. 2007	Abraham et al. 2007	Arditi et al. 2007	Hancher et al. 2007	Ullman et al. 2008	Miller et al. 2009
Research Method												
Surveys	N			N	N		N	N	N	N		
Interviews								N				
Focus Group										N		
Field measurements:												
LUMINA		N										
Speed data												N
Crash data						N					N	
Accidents data				N			N		N		N	
Site test			N									
Observational studies				N								N
Statistic data/analysis										N		N
Solutions												
Personal protection equipment (PPE)	N	N	N		N		N	N				
Different site conditions – lighting, weather, traffic volumes	N	N							N			
GC safety plans								N				
Management techniques								N			N	
Crash rates				N		N						
Traffic control planning							N	N				
Speed control								N				N
Accident factors	N	N			N		N			N		
Innovative technique										N		

N = Nighttime, G = General

Crash causal factors have been investigated through examination of traffic accident and crash data. Data maintained by STAs and other agencies were obtained and studied by Ullman et al. (2008). Traffic accident data for the study conducted by Arditi et al. (2007) were downloaded from the FTP site in the web-based Encyclopedia of Fatality Analysis Reporting System (FARS) that is serviced by the National Highway Traffic Safety Administration (NHTSA).

2.2.3 Approaches

To address these safety issues, a number of options have been explored. The options include PPE, general contractor (GC) safety plans, management techniques, and innovative techniques. Traffic control (TC) plans and speed control have been investigated in relation to the safety of the worker, as well as for the safety of the traveling public.

PPE is the most-researched topic in this area. Many of the research reports investigate the use of reflective vests and other garments. Sayer and Mefford (2004) studied methods for improving the reflectivity of PPE garments. They found that personal safety garments incorporating retro-reflective trim significantly improve worker conspicuity in work zones, particularly if the trim is located on garment sleeves.

Hirasawa et al. (2007) investigated the visibility of traffic control personnel during nighttime work. They found the color of the garment has a dramatic impact on the safety of the worker. A color change to orange or yellow was suggested by the research. In addition to the aesthetics of the PPE garments, Hancher et al. (2007) determined the garments must also be comfortable.

In 2003, Arditi et al. followed up on the previous research to determine that the vest that has been adopted by the Illinois Department of Transportation (IDOT) performs best in the various work-zone conditions when compared to other high-visibility garments in the study. Later, Arditi et al. (2004) found that the effectiveness of the vests depends not only on the vest characteristic, such as reflectivity or color, but also on site conditions. Site conditions that are found to have an impact on the effectiveness of the vests are lighting, traffic, and weather.

Some literature reports on contractor safety plans and different types of management techniques as a solution in this area. Abraham et al. (2007) conducted a study on contractor safety management planning for nighttime construction and maintenance operations. The researchers found that contractors are becoming more involved in traffic-control planning. However, the training and experience of those involved in the planning varies among contractors and this has an impact on the quality of nighttime planning. Different types of management policies, procedures, and practices have been identified as solutions to improve nighttime and daytime work-zone safety (Ullman et al. 2008).

Traffic-control planning and speed control can enhance safety for both construction workers and the traveling public. A highly-visible traffic control set-up is important (Hirasawa et al. 2007). Abraham et al. (2007) furthered this discussion by suggesting that speed control is imperative. Speed control can also be achieved by increasing police presence, enforcement, and signage (Abraham et al. 2007, Miller et al. 2009).

Several states, including Washington and Arizona, are using automated speed enforcement with traffic tickets from a mobile van in work zones. In addition, the use of cones and barrels and the length of the taper play a key role in controlling traffic and speed (Miller et al. 2009).

Researchers also found the number and ratio of trucks and personal vehicles on the road has an impact on the speed of traffic (Abraham et al. 2007, Miller et al. 2009), so site traffic conditions were to be taken into account when planning methods to control speed.

Innovative techniques for reducing the traffic speed in work zones include police disguised as construction workers, the use of a mobile work-protection system that uses a modified semi-trailer (called the Balsi Beam), and robotic safety cones (Hancher et al. 2007; FHWA 2004).

2.3 Construction Nuisances

Nighttime construction nuisances that have the potential to disturb adjacent property owners include noise, vibration, light, and dust effects of work activities. Project design can address construction nuisances by locating and sequencing construction operations to minimize their impacts. Current practices, such as source control, path control, and receptor control, are helpful in eliminating or minimizing the effect of nighttime construction noise and lighting nuisances. These practices are well documented in the literature.

2.3.1 Problems

The major nuisances associated with nighttime construction are noise, illumination, and vibration (Schexnayder and Ernzen 1999). Noise problems are normally caused by the operation of heavy equipment, and specifically by vehicle and machine backup alarms. While good illumination is necessary for the work to proceed at night and for the safety of the traveling public, proper work-zone illumination can be very intrusive to project neighbors. Vibration problems are primarily a result of pile driving, blasting operations, or the use of vibratory rollers. STA personnel are also concerned by exposure to possible contractor claims if noise objectives are not properly presented in the contract documents.

The problems associated with nighttime construction are very location dependent. A previous survey of STAs found that major problems with nighttime construction nuisances are experienced by agencies with a significant portion of their work in highly-urbanized environments (Schexnayder 1999). Nighttime construction often causes problems when the work is in residential and commercial areas; whereas, in rural settings or when resurfacing a highway in an industrial area, problems are few. Agencies qualified their problem ratings with statements like “site specific.” In an earlier study, 27 state agencies reported serious nighttime construction nuisance problems (Schexnayder and Ernzen 1999).

From earlier studies and support by a recent National Cooperative Highway Research Program (NCHRP) study on Accelerated Construction, it is evident that, for projects involving nighttime work, the “contract documents, must clearly define work restrictions (e.g., work-hour restrictions, vibration and noise restrictions, and any regulations that will limit work or logistic activities). These restrictions must be further delineated as to their application to activities during daylight hours or to evening and nighttime hours with definitions of the terms daylight, evening, and nighttime clearly stated” (Anderson and Schexnayder 2009).

It appears that nuisance problems are a function of the nature of the nighttime work performed and the location of that work. Agencies experienced limited nuisance problems when conducting nighttime activities of paving, patching, or resurfacing operations on interstate highways. These operations typically take place where the background noise from the traffic muffles the construction noise. In addition, this type of work involves operations that are constantly moving and, therefore, affect a receiver for only a limited time duration.

A number of STAs indicated they require adherence to certain noise (decibel) limits during nighttime construction (as in New York City). In many cases, these limits are the consequence of specific local ordinances. However, some STAs indicated they could receive local ordinance waivers rather easily. Others stated they had jurisdiction over the local municipalities in these matters, but that they tried to abide by the local ordinances.

An example of noise problems that can arise, even when an STA tries to conform to local regulations, is the case of the Florida Department of Transportation (FDOT) experience with the SR9A corridor work. One SR9A contract within the Jacksonville municipal limits caused the FDOT significant problems. FDOT experienced contractual, claim, and community issues during the work because of noise caused by nighttime work. Though FDOT does not have to abide by the city’s regulations, it sought, by contract language, to make contractors aware of the noise ordinance and hold them in conformance. Contract language used to inform contractors of the Jacksonville Noise Ordinance included:

> FDOT Standard Specifications: Section 7, Article 7-1 **Laws to be Observed**, Sub-article 7-1.1, “The contractor is required to become familiar with and comply with all Federal, State, county and city laws, by-laws, ordinances and regulations that control the actions or operation of those engaged or employed in the work or that affect materials used.”
>
> FDOT Standard Specifications: Section 8, Article 8-4 **Limitations of Operations**, Sub-article 8-4.1, “Night Work,” “The contractor is required to comply with all applicable regulations governing noise abatement.”
>
> Plan Sheet M-13 **Pile Driving**, Note 1 stated, “All pile driving activities are subject to the Noise Ordinance of the City of Jacksonville.”

> **Addendum 2** which was written in Response to Requests for Information from the Mandatory Pre-Bid Meeting included the following: "Regarding noise restrictions, refer to Sheet M-13. For additional information regarding the Jacksonville Noise Ordinance, please contact XXXX with the Duval County Air and Water Quality Office at (904) xxx-xxxx.

Even with these notices about noise limitations imposed on project work hours, there were complaints that FDOT hindered the contractor's efforts to secure the offered project bonus. Reference to nighttime noise rules or regulations that seem clear can cause misunderstandings and arguments when they affect the contractor's ability to complete a project within contract-specified time limits.

2.3.2 Study Methods

The most used methodology for studying construction operations has been the case study approach. This research project assembled case study information through the literature review and surveys conducted with transportation-agency representatives, contractors, and engineering consultants, who had nighttime project experience.

These first two tasks of the NCHRP Research Project—literature review and surveys—are not an all-inclusive review of current activities. Rather, they document an attempt to identify the key factors that lead to successful delivery of nighttime construction projects and control of nuisances. The authors and agency professionals used their professional expertise and experience to derive qualitative judgments concerning identification of significant nuisances and methods of nuisance control.

The information gained in Task 1 serves to identify best practices in terms of source control, path control, and receptor control (see Table 2.5).

2.3.3 Approaches

Community relations are the key to the mitigation of nighttime construction nuisance problems. Early communications with project neighbors and the public is indispensable in creating a bond of trust and cooperation. Inform project neighbors and the public of any potential construction noise, light, and vibration impacts and the measures that will be employed to reduce the impacts. Establish and publicize a responsive complaint mechanism. The establishment of a good rapport with the community can provide immense benefits at low cost.

Project design also has a major impact on the generation of construction nuisances. Early coordination and communications with project designers can aid in locating and sequencing construction operations to minimize potential construction impacts at sensitive receptors. The use of any existing natural or artificial features that can shield the construction noise and light should be accounted for in the project design. Permanent project noise barriers should be constructed as early as possible to reduce potential construction visual and noise impacts.

Table 2.5. Construction nuisances literature*

	Authors									
Methodology and Solutions	Ferguson 1995	Schexnayder 1999	Thalheimer 2000	Schexnayder 2001	Thalheimer 2001	Gilchrist et al. 2003	WSDOT January - March 2003	WSDOT April - June 2006	Gannoruwa, Ruwanpura 2007	Schexnayder (FHWA) 2009
Research Method										
Literature review	G	N		N						N
Field measurements										
Simulation						G			G	
Modeling									G	
Observation/visit			G		G		G	G		
Demonstration										
Experiments/lab						G				
Solutions										
Noise control mitigation strategies/methods/ programs	G	N	G	N	G	G	G	G	G	N
Development of system/design/ model						G			G	
Guidelines/spec			G							

N = Nighttime, G = General

* *FHWA Construction Noise Handbook* (http://www.fhwa.dot.gov/environment/noise/handbook/ref.htm#r033) provides another 81 references.

Communities are concerned about the overall impact resulting from construction sites. It is important to assess the background conditions of a project site and to realize the differences in background conditions that exist at night. The project design must allow the contractor a means to accomplish the work while conforming to a desired impact level at the receiver. Mitigation of nuisances should consider source, path, and receptor controls, in that order.

Source control is the most-effective method of eliminating nighttime construction nuisances. Source controls, which limit noise, light, vibration, dust emissions, and other nuisances, are the easiest to oversee on a construction project. Mitigation at the source reduces the problem everywhere, not just along one single path or for one receiver. Construction equipment is a major noise and nuisance generator on nearly all nighttime construction projects. The specification of equipment noise-emission limits forces the modern equipment to have better engine insulation and mufflers.

Path control of nuisances should be implemented when source controls prove insufficient in adequately minimizing impacts on abutting sensitive receptors. This situation can result due to the close proximity or because of the very nature of the construction work. Thus, having exhausted all possible mitigation methods of controlling a nuisance at the source, the second line of attack is controlling noise, light, vibration, or dust radiation along their transmission paths. When barriers are used, they should provide a substantial reduction in noise levels, be cost-effective, and be implementable in a practical manner, without limiting accessibility.

Receptor control of a nuisance must be undertaken when all other approaches to mitigation have failed. It should be remembered that the critical receiver might not be a human. For example, certain precision equipment is sensitive to very low levels of ambient noise and vibration. In addition, the response of human beings, either singularly or as a group, is a problem due to the individuality of each person. No one individual is likely to exhibit the same reaction to a noise stimulus on two successive days. Furthermore, the reality is that some individuals are simply hypersensitive. The receptor problems usually involve individuals located very close to the nuisance-generating activity, in which case it may be easier and more effective to improve the individual’s environment, instead of controlling all emitted noise, vibration, or dust.

Widening and rehabilitation work will constitute a significant number of the projects that agencies build in the future and many of these projects will be in urban locations, where daylight highway construction closures cause unacceptable congestion problems. Consequently, the construction of a significant number of these future projects will take place at night. Therefore, it is important that before contracts are advertised and bid, there be an objective assessment as to the magnitude of nighttime construction nuisances. Noise problems are normally caused by the operations of heavy equipment. The identification of methods and techniques for mitigating such nuisances is a critical requirement for conducting agency business in a responsible manner, and for preparing applicable contract documents.

When queried regarding the generators of the nuisances, many of the agency responses were very similar. Backup alarms and slamming tailgates were the most frequent answers.

Demolition equipment used in pavement breaking and bridge deck removal was another frequent problem generator. Therefore, it is obvious that particular attention should be paid to projects that require a large fleet of haul trucks operating at night. In the case of such projects, backup alarms should be the least-intrusive and least ambient-sensitive type, or the contractor should use a backup observer, and it may be necessary to establish truck clean-out staging areas for mitigation of banging tailgates.

Agencies can influence the construction environment by using controlling specifications. A good construction specification is an effective tool in mitigating the effect of nighttime construction nuisances (see Table 2.6). The mechanisms to achieve the goal of controlling nuisances will vary from contract-to-contract, because of area-specific conditions, the type of construction, the inherent noise-reduction qualities of affected receptor structures, and the desires of the affected abutters.

Supplemental standard provisions can specify mitigation measures on a contract-by-contract basis to address special local-condition noise, light, and vibration desires. The criteria for allowable maximum noise levels and working hours should reflect the noise sensitivity of adjacent neighbors. It may be necessary to have specific noise mitigation measures specified for various work items. The existence and importance of nuisance control specifications should be emphasized at pre-bid and pre-construction conferences.

When the requirement to comply with all restrictions and commitments is included in the contract documents, contractors can be expected to allow for compliance in the bid price. Such an approach allows contractors to plan their operations effectively and to seek innovative solutions to the clearly-identified problem. This approach will minimize the potential complaints, and serve to control construction cost and delays.

2.4 Communications Strategies

A variety of methods are available to agencies to disseminate information about nighttime construction projects (Shepard and Cottrell 1986 and 1984). The most common medium of communication is newspapers, followed by the radio and television. However, special signs and door-to-door contacts are effective means of communicating the information.

2.4.1 Problems

The public does not always understand or appreciate the need for nighttime construction work; therefore, communications are a vital component of successfully accomplishing a nighttime construction project. It is important to maintain positive community relations in unison with the implementation of actual construction nuisance abatement measures.

Table 2.6. Agency policies and reference materials on construction nuisances

State	Policies and Reference Materials
Alaska	http://www.dot.state.ak.us/stwddes/desenviron/index.shtml /
Arizona	http://www.azdot.gov/Highways/EPG/EPG_Common/Documents_Technical_Noise.asp
Arkansas	http://www.arkansashighways.com/evironmental/noise.aspx
California	http://www.dot.ca.gov/hq/oppd/pdpm/chap_pdf/chapt30.pdf *Related Information:* Caltrans-Highway Design Manual-Ch1100-Highway Traffic Noise Abatement http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp1100.pdf
Colorado	www.dot.state.co.us/environmental/CulturalResources/Noise.asp
Connecticut	*Related Information:* Guide to Understanding Traffic Noise General Conditions - Environmental Compliance
Florida	http://www.dot.state.fl.us/emo/pubs/pdeman/Chapter%2017%204-18-07FINAL.pdf *Related Information:* http://pubsindex.trb.org/view.aspx?id=813314
Georgia	http://www.dot.state.ga.us/informationcenter/programs/environment/NEPA/Documents/NoisePolicy-2011.pdf
Idaho	http://itd.idaho.gov/manuals/Online_Manuals/Environmental/Environmental.htm
Illinois	www.dot.il.gov/desenv/noise/part1.html
Indiana	http://www.in.gov/indot/files/INDOTNoisePolicy%281%29.pdf
Maine	http://www.maine.gov/mdot/aqn/
Massachusetts	*Related Information:* Central Artery Construction Noise Specification
Michigan	www.michigan.gov/mdot/0,1607,7-151-9621_ 11041_25846---,00.html
Minnesota	http://www.dot.state.mn.us/environment/noise/index.html http://www.dot.state.mn.us/environment/noise/pdf/2011mndotnoisepolicy.pdf
Montana	http://www.mdt.mt.gov/business/contracting/environmental/air_noise.shtml
New Jersey	www.state.nj.us/transportation/eng/documents/BDC/doc/bdc03t05.doc www.state.nj.us/transportation/eng/documents/miscref/noisestudy.shtm www.state.nj.us/dep/enforcement/ *Related Information:* New Jersey Model Noise Ordinance
New York	https://www.nysdot.gov/divisions/engineering/environmental-analysis/noise-analysis see Chapter 3 at: https://www.nysdot.gov/divisions/engineering/environmental-analysis/manuals-and-guidance/epm/chapter-3#chapt3
North Carolina	www.ncdot.org/doh/preconstruct/pe/ohe/NoiseAir/ www.ncdot.org/doh/preconstruct/pe/ohe/NoiseAir/abatement.html
Ohio	http://www.dot.state.oh.us/Divisions/Planning/environment/nepa_policy_issues/noise/Pages/default.aspx
Oregon	ftp://ftp.odot.state.or.us/techserv/geo-environmental/environmental/procedural%20manuals/Air%20and%20Noise/ODOT%20Noise%20Manual.pdf
Pennsylvania	ftp://ftp.dot.state.pa.us/public/pdf/pennDOTpub24.pdf
Tennessee	http://www.tdot.state.tn.us/news/2005/030405.htm

State	Policies and Reference Materials
West Virginia	Noise Guidelines are contained at the following web site under Coordination/Environment (DD 207); Mitigation Directive is DD 206: http://www.transportation.wv.gov/highways/engineering/DD/2006%20DD%20Manual%20MASTER.pdfm
Wisconsin	Facilities Development Manual, Chapter 23 Noise: http://roadwaystandards.dot.wi.gov/standards/fdm/23-45.pdf

Public involvement creates a bond of trust and helps to eliminate potential problems before they become major issues. To be successful, community awareness efforts must be championed by top management, be integrated into the project development process, and continue during the construction phase. Several STAs (Arizona, Massachusetts, and Utah) have extensive experience in these types of activities.

Possible impacts should be identified and addressed when working with local governments and project neighbors. In addition, the public should be given the opportunity to provide timely input. It is good business to conduct public hearings. These can be important to ensure that the public is informed, receive feedback, and provide early identification of controversial issues. The objective is to notify local governments and affected businesses and residents. It is imperative that the details of the proposed construction phasing and methods be explained. Methods for achieving better communications with the public have been studied by a number or researchers (see Table 2.7).

2.4.2 Study Methods

Various means of communicating with the public about the construction activities taking place have been practiced, based on past precedence in different construction projects. Currently, most construction projects use the same methods in delivering information pertaining to construction projects, without regard to the work being daytime or nighttime.

2.4.3 Approaches

Delivering information pertaining to construction work, regardless of daytime or nighttime operations, is essential. The public should be told by the respective agencies and contractors about the construction activities that are taking place in their neighborhoods. By exercising effective communications strategies, there will be an increase in public and safety awareness. In addition, problems that arise due to construction activities will be appropriately addressed by the public, according to the information provided.

The research identified many successful ways to ensure effective communications between transportation agencies and the public. Newsletters and news reports provide information to the public about construction projects. Other commonly-adopted communications strategies are public hearings, press releases, special mailings, personal contact, special signage, community outreach, campaigns, internet, and hotline numbers.

Table 2.7. Communications literature

	Authors							
Method and Study Area	Hinze, Carlisle 1990	Schexnayder 1999	Schexnayder, Ernzen 1999	Schexnayder 2001	Bryden, Mace 2002a	Gilchrist et al. 2003	WSDOT January - March 2003	WSDOT April - June 2006
Communication methods								
Public hearings								
On television	N				N			
Press releases								
Newspaper	N		N		N			
Radio	N		N		N			
Television	N		N		N			
Special mailings	N	N		N	N		N	N
Personal contact								
Special gathering				N				
Door-to-door				N				
Local officials				N	N	N		
Special signage	N				N			
Community outreach			N		N			
Campaigns	N				N			
Internet/web			N		N		N	N
Phone service		N	N				N	N

N = Nighttime, G = General

Special mailings are a leading communication method recommended by researchers. Schexnayder (1999), Schexnayder (2001), Bryden and Mace (2002a) and The Washington State DOT (WSDOT) reports in January – March 2003 and April – June 2006 confirmed this in their findings. Different techniques of special mailings have been used to convey public information, including agency newsletters, notices in utility billings in either letter or memo form, registered personalized letters, notices, and even telegrams (Hinze and Carlisle 1990).

Other common techniques for communicating with the public are through websites and hotline contact numbers. While newspaper, television, and radio notices are among the most well-used communication methods (Hinze and Carlisle 1990, Schexnayder 1999, and Bryden and Mace 2002a), electronic means are gaining acceptance. Some agencies and contractors provide information on their websites.

Having a single point of contact at the main office of the agency is part of effective communications. Techniques like special signage and community outreach are mentioned by Bryden and Mace (2002a). In addition, according to Bryden and Mace (2002a), community input can best be addressed in the planning stages of the project, by involving community groups in the process and providing good communications on project community impacts. In addition, once work begins, it is important to provide a mechanism for ongoing community input.

Concerns will more likely be voiced at the district level of an agency, although some complaints and concerns may be addressed directly to the project staff, the central office, or local public officials. Publicizing contact phone numbers and addresses in the local media and to local officials help members of the community channel concerns to the proper individuals.

From the previous studies, it is clear that nighttime construction generates more comments and community concerns about work activities. The probability of community input increases in urban areas, especially when commercial and residential areas are involved. Therefore, it is important to recognize in advance that night work will generate community comment and that adequate mechanisms should be in place to allow input and provide timely responses (and, responses need to be almost immediate).

2.5 Illumination

One of the major issues of concern in nighttime construction operations is that of lighting and illumination. Lighting and illumination problems resulting from nighttime highway construction work zones have been the topic of extensive research. Studies of lighting and illumination are summarized in Table 2.8.

Table 2.8. Illumination literature

	Authors											
Methodology and Study Area	Luoma et al. 1995	Ellis, Amos 1996	El-Rayes, Hyari 2002	Khan 2003	El-Rayes, Hyari 2005a	El-Rayes, Hyari 2005b	Freyssinier et al. 2006	Hyari, El-Rayes 2006a	Hyari, El-Rayes 2006b	Patangia 2007	Nassar 2008	Figueiro et al. 2009
Method												
Surveys				N						N		
Interviews												
Framework								N			N	
Literature review		N				N						
Field measurements												
Simulation							N			N		N
Modeling			N		N							
Design					N							
Observation/visit		N										
Demonstration		N										
Modules					N							
On-site testing/method	N						N	N	N			
Experiments/lab												N
Findings												
Development of device										N		
Development of system/design/model			N	N		N					N	
Guidelines/spec		N										
System benefits and performance							N		N		N	
Retroflection	N											
Visibility/lighting												N
Illuminance						N		N				

N = Nighttime, G = General

2.5.1 Problems

Vision, visibility, and light-pollution problems are regularly encountered during nighttime construction work. Nighttime construction activities require the creation of adequate lighting conditions and therefore project specifications often require contractors to submit lighting plans. These plans show the lighting design parameters, including equipment: number and type, location, mounting height, angle of rotation, and spacing. The plans are usually reviewed by the agency before the commencement of the project and are checked for their conformance to lighting requirements (El-Rayes and Hyari 2005a).

The main challenge faced by contractors and agencies in the creation and review of lighting plans is the extent of the computations required. This challenge has resulted in research on the creation of practical models for the design and evaluation of work-zone lighting (El-Rayes and Hyari 2005a).

One challenge in the creation of project lighting design is the use of temporary lighting towers. Lighting towers are characterized by their relatively low luminaire mounting heights compared to permanent highway lighting arrangements (Freyssinier et al. 2006). This creates a potential for shadows and glare to workers and the traveling public. Another challenge with the use of temporary lighting arrangements is the cost and duration required for deployment and dismantling (Freyssinier et al. 2006).

In addition to these problems, there is often an insufficiency in the lighting provided to perform the construction task properly. The level of lighting needed for specific construction activities depends on factors related to the humans performing the activities, as well as factors relating to the task at hand and the environment in which it takes place (Ellis 2001). Therefore, in creating lighting standards, reasonable visual abilities considered normal are assumed, while giving some allowance for variations among workers.

The task-dependent factors used in creating visual standards are listed in Table 2.9 (Ellis 2001).

Table 2.9 Task-dependent factors for visual standards (Ellis 2001)

Factor	Description
Required Accuracy	The higher the precision required in a task, the higher the level of illumination it needs
Background Reflection	The ability to visualize an object or a target depends on the contrast between that object and the background behind it
Relative Speed	The relative speed of the object/target or its observer is another factor directly affecting the level of lighting needed for the construction task
Object Size	The size of the target observed in construction tasks impacts the level of illumination in the task
Seeing Distance	The distance between the observer (construction labor) and the target in each task is another determinant factor in setting levels of illumination

These factors have been used to determine illumination standards in a number of industries. A number of studies have focused on determining suitable lighting levels for highway construction activities (Ellis 2001).

Table 2.10 shows the levels of illumination that were found to be necessary for major construction activities.

Table 2.10. Required illumination levels for highway construction activities (Ellis 2001)

Lighting Category	Minimum Illumination (lx)	Area to be Illuminated	Type of Work Activity	Sample Activities
I	54	Illumination throughout the work area	General work area lighting, and performance of visual task of large sizes, or medium contrast, or low required accuracy	Excavation Sweeping General lighting of all work areas and movement areas between tasks
II	108	Illumination of work area and areas adjacent to equipment	Performance of visual tasks of medium size, or low to medium contrast, or medium required accuracy	Paving Milling Work areas for the active paving operation
III	216	Illumination of task	Performance of visual tasks of small size, or low contrast, or high required accuracy, or fine finish	Crack filling Signalization systems Lighting applied directly to the task

A detailed study that determined the appropriate levels of illumination for highway construction activities analyzed both human factors and task factors (Hyari and El-Rayes 2006b). In this study, highway construction activities were surveyed to determine the smallest objects that workers needed to see while performing the task. This study also looked at the contrast between that critical detail and the background. Finally, the study determined the reflectance factor of targets in each activity, which was measured as a ratio of target luminance to the level of luminance in the surrounding environment.

These parameters were used to determine the required level of visual performance that the workers performing the work need to have (Hyari and El-Rayes 2006b). This required luminance for each task could be converted into its equivalent illuminance level by dividing the luminance value by the reflectance factor determined for the task. These steps were implemented in a model called CONVISUAL (Hyari and El-Rayes 2006b), which was tested on pavement marking activities.

In another study, a survey was conducted of lighting levels in highway construction operations in the US. Lighting levels were found be to be adequate for most tasks, although some tasks were not found to have sufficient levels of illumination. The reason for insufficient lighting levels was mainly the result of inappropriate lighting equipment selection and improper setup. This issue was found to be more prevalent for equipment operations, such as compaction of pavements with rollers (Ellis et al. 2003). The operators relied on their experience and were unable to find missed locations. In addition, a number of other activities were found to have inadequate lighting levels. These activities included the paving of intersections, especially in tasks relating to the hand spreading of the paving mix, and bridge construction. For most of the observed operations, lighting was found to be sufficiently uniform. The exception was milling and repaving operations, where uniformity was difficult to maintain due to the continuous movement of the construction operations.

Luminaires that had good diffusion had a good level of lighting uniformity. Flood light towers were found to provide well-diffused lighting, leading to better lighting uniformity than construction equipment-mounted lights (Ellis et al. 2003). A lighting quality factor that was found to be inadequate was lighting direction, especially when using lighting towers. Lighting towers were found to be placed too close to the open traffic lanes and, in some cases, pointed toward incoming traffic. In other cases, lighting towers were placed in locations that led to their creating shadows on the construction task being performed (Ellis et al. 2003). Improper lighting arrangements adversely impacts quality, given defects are less visible to inspectors (Hyari and El-Rayes 2006a).

The inappropriate direction of lighting led to tasks being performed in negative contrast rather than a positive one. Spotlights mounted on construction equipment had better light direction. However, the mounting height of some of these spotlights was found to be too low, which led to light falling on the equipment wheels instead of on the operation. Machines that had factory-installed spotlights were found to have better lighting directivity. In all observed operations, the levels of veiling glare were found to be negligible due to the low reflectivity of surfaces in highway construction operations (Ellis et al. 2003).

Workers in highway construction operations were found to experience direct glare more than workers on bridge projects. The glare experienced by the traveling public was found to be excessive in highway operation, where lanes adjacent to the construction operations were open to traffic. This glare was lower in environments where permanent roadway lights were available, due to the lower background contrast. Finally, it was observed that the lighting design processes practiced by contractors were all very basic and, in some cases, there was no clear process behind the selection of the location, positioning, and orientation of the lighting equipment (Ellis et al. 2003).

In addition to these challenges, lighting conditions within a construction work zone may contribute to the problem of light pollution. Light pollution is caused by light leaving the boundaries of the project. The main three phenomena associated with light pollution are sky glow, light trespass, and discomfort glare. These were found to be independent of each other, but each is measurable, predictable, and therefore, controllable. Lighting arrangements can be designed to minimize these three light-pollution phenomena.

Sky glow depends, to a large extent, on the illuminance that lighting arrangements provide on horizontal surfaces of the construction work zone. Large sites need higher levels of illumination, and therefore, produce more sky glow. Sky glow also increases with higher levels of surface reflectance. Therefore, one possible indicator of sky glow could be the reflectance factor of the surfaces in the construction work zone (Brons et al.2008).

Light trespass is defined as artificial lighting that intrudes into areas where it is not wanted or does not belong. Light trespass, therefore, needs to be controlled to ensure that lighting arrangements do not excessively spill light over into adjacent properties (Hyari and El-Rayes 2006a). Theoretically light spill-over can enhance safety and security in adjacent properties; nevertheless, most property owners' find this light to be undesirable (Khan 2003). The main method for measuring light trespass is to measure a parameter called vertical illuminance, at the edge of the affected property. This vertical illuminance is measurable using a simple illuminance meter, but measurements have to be taken at vertical heights representing the plane of the observer's eye at possible viewing locations of the light source. A number of standards have recommended maximum vertical illuminance levels to control light trespass. The Illuminating Engineering Society of North America (IESNA) recommends maximum vertical illumination levels ranging from 1 to 15 lux, depending on the time of night and the type of land use in the area surrounding the lighting arrangements (Hyari and El-Rayes 2006a).

Glare is a more difficult phenomenon to measure, compared to sky glow and light trespass. A number of methods have been developed to measure glare to workers, the traveling public, and surrounding properties (El-Rayes and Hyari 2005a, Hyari and El-Rayes 2006a, Khan 2003, Brons et al.2008).

In addition to the above described direct challenges associated with lighting arrangements, illumination has been reported to impact construction operations during nighttime work zones indirectly. A number of studies have shown that lighting arrangements have an impact on safety, quality, cost, and productivity in nighttime construction work (El-Rayes and Hyari 2005a). Insufficient lighting, for example, has been shown to increase worker injury rates. Improper lighting arrangements cause glare hazards to workers and drivers, and glare has an impact on nighttime construction safety (Hyari and El-Rayes 2006a). It was shown that nighttime construction operations are more hazardous to the traveling public than daytime operations. It was estimated that half of all fatal work-zone crashes occur at night (Freyssinier et al. 2006). This percentage is very high when viewed in the context that only a quarter of driven mileage takes place at night (Freyssinier et al. 2006).

Exposure to light, even for a brief amount of time of 15 to 30 minutes, has been shown to have a positive impact on levels of alertness, wakefulness, and performance in certain tasks. Experiments conducted on human subjects have shown that exposure to bright lights reaching 5000 to 10,000 lux (which is about 50 to 100 times the required lighting on a work zone) led to higher alertness and performance than exposure to dim lights between 10 and 100 lux. This exposure was shown to correlate well in a number of studies with objective measures of alertness such as an electroencephalogram (EEG), which measures the electrophysical activity of the brain. These tests showed that this increase in alertness takes place regardless of the time on the circadian clock (Figueiro et al. 2009).

2.5.2 Study Methods

The quality of work-zone lighting has been evaluated using three parameters and project specifications usually focus on these three parameters:

- Illuminance
- Lighting uniformity
- Glare

Most standards require a minimum level of average illuminance to be provided. This ensures the intensity of light incident on the surfaces of the project. Illuminance represents the time rate of flow of light measured in lumens that falls upon a surface area. The unit of measurement of illuminance is lux, which is measured in lumens/m^2. Illuminance can be measure on a job site using a simple device called the illuminance meter (Hyari and El-Rayes 2006a).

The amount of lighting available for performing a specific task can be also measured using luminance. This measure is often confused with the above describe illuminance measure; therefore, it is important to distinguish between these two measures. Illumination is a measure of the amount of light incident on a unit surface area as explained above. Luminance, on the other hand, is the amount of light (measured in luminous flux as well) *leaving* a surface at a given time. Luminance, therefore, is measured in candelas per square meter, and is more suitable for measuring visibility of objects (Ellis 2001). Given that luminance needs a target for which measurements are taken, its measuring devices allow users to focus on specific targets from the distances they desire.

Another criterion that specifications require is the level of light uniformity, which ensures that lighting is distributed uniformly to all areas of the job site. Lighting uniformity is used to evaluate the suitability of lighting arrangements in work zones. Lighting uniformity is calculated as the ratio between the above described average illuminanceE_{ave} and the minimum illuminance at the darkest spot on the job site E_{min} (El-Rayes and Hyari 2005a). It is important to note that smaller values of this ratio are better, because they indicate a smaller difference between average illuminance and the levels of lighting at the darkest spot on the job site (Nassar 2008).

Finally, agencies specify maximum glare, which is quantified using the levels of luminance prevalent on site (El-Rayes and Hyari 2005a). Unlike lighting uniformity, glare calculations are dependent on luminance values prevalent on the job site. To consider luminance, the reflectance characteristics of the surfaces present in the job site must be considered. The largest surface that needs to be considered is naturally the pavement surface in the work area, which is classified into four main categories by the Illuminating Engineering Society of North America (IESNA), based on the ability of the pavement material to reflect light (El-Rayes and Hyari 2005a). These pavement reflectance characteristics are used to determine the luminance of the pavement.

Maximum computed glare is the measure used to determine the suitability of work-zone lighting arrangements (El-Rayes and Hyari 2005a). The importance of pavement luminance stems from the fact that the sensation of glare depends on the amount of veiling luminance workers experience relative to the level of luminance their eyes were adapted to when they were exposed to this veiling luminance (i.e. pavement luminance).

Work-zone lighting design models have been developed to optimize the above described lighting quality parameters. The objective of lighting design models is to select and/or optimize a number of parameters to achieve adequate and/or optimum levels of illuminance, uniformity, and glare (El-Rayes and Hyari 2005a; Nassar 2008). In addition, a number of field studies have been conducted to evaluate work-zone lighting conditions. Some of these studies had the objective of validating the outputs of lighting design models. Others focused on the evaluation of innovative work-zone lighting solutions.

Field experiments have been performed to evaluate lighting arrangements commonly found in highway work zones. These experiments evaluated the performance of lighting arrangements in three of the four main work-zone areas defined by the Manual on Uniform Traffic Control Devices (MUTCD):

- Activity areas
- Transition areas
- Flagger station areas

Experiments that were conducted at the Advanced Transportation Research and Engineering Laboratory (ATREL) at the University of Illinois utilized a number of lighting towers to evaluate transition and termination area lighting. Lighting arrangements in these areas are of critical importance, given they allow drivers to adjust to the higher levels of illumination from the relatively dark roadways on which they were driving.

Transition lighting is also important in allowing drivers to recognize the construction work zone from a far distance, which gives them a chance to adjust to the change in driving conditions. Transitions areas need to have gradually-increasing levels of illumination, while termination areas need to have gradually-decreasing levels of lighting (Hyari and El-Rayes 2006a).

The main requirement for lighting levels in transition areas comes from the New York State Department of Transportation (NYSDOT) and an NCHRP study (Ellis et al. 2003). The experiments showed that, although a rather larger number of portable lighting tripods were needed (16 in a 200m transition area), it was still a more cost-effective solution than renting the needed four lighting towers for achieving the same level of illuminance. The added advantage of using these lighting tripods was that the tripods provided better lighting uniformity than lighting towers, and their performance characteristics are expected to improve even further if tripods with higher mounting height are used (Hyari and El-Rayes 2006a).

Other experiments conducted in this field study evaluated lighting arrangements for flagger stations. The purpose of providing lighting for flagger stations is to ensure that flaggers are clearly visible to drivers. Standards for flagger station lighting require minimum average illuminance of 108 lux. The main concern with arrangements providing this level of lighting is that they can cause glare to drivers and the flagger. Therefore, NCHRP recommended that the lighting for flagger stations be provided from above flaggers instead of in front or behind them (Ellis et al. 2003). The experiments evaluated the use of lighting tripods positioned so that their luminaires were mounted 3m from the ground and were aimed straight down to the ground to prevent glare to drivers or to the flagger, and this provided the required level of illuminance without causing objectionable glare (Hyari and El-Rayes 2006a).

The Oregon DOT (ODOT) conducted a field experiment that evaluated lighting arrangement for highway nighttime construction work, focusing on lighting arrangements for flagger operations. The study answered a number of research question concerning (1) location and direction of the light source used, (2) level and quality of lighting needed to practically and economically illuminate flagger operation without causing glare to traffic, and (3) the level of mobility of lighting equipment and the level of risk to flaggers in using such mobile lighting equipment.

The study had the objective of developing guidelines for optimal illumination of flagger stations, which includes minimum and optimal lighting levels and methods of achieving these levels with the highest level of flexibility (Gambatese 2005). The first type of lighting equipment used was a light tower similar to the ones used in the study conducted at ATREL and included four luminaires each containing a 1,000 watt metal halide lamp. The second type of equipment used was a new type of lighting called balloon lighting.

Balloon lighting is composed of a fabric balloon that is inflated with air or helium that can be mounted on a stand, tripod, or vehicle. The fabric of the lower half of the balloon is designed to remove any possible glare from the light it produces. The balloon usually includes a single luminaire that uses either a halogen lamp or a hydrargyrum medium-arc iodide (HMI) lighting system. The balloon allows for the distribution of lighting over 360 degrees and can be mounted to heights reaching 164 ft. The balloon lights that were tested included a system that was supported by a backpack carried by construction workers that had a 1.5 ft diameter balloon. A tripod system that could extend from 8 to 15 ft and a balloon with a 3 ft diameter were also tested (Gambatese 2005).

IDOT has also conducted studies of the veiling luminance (glare) experienced by drivers passing through highway construction work zones. The main objectives of the IDOT study were to (1) study factors that impact the measurement of glare in and around work zones, (2) compare the glare levels produced by typical lighting arrangements in construction work zones, (3) measure the impact of lighting design parameters on glare levels, (4) create a practical model that could be used by the STA and contractors to quantify glare levels, and (5) evaluate design requirements for levels of glare and the levels of glare that could be tolerated by drivers in the work zone.

The study included field visits to highway construction projects and field experiments. The main findings of the field visits illustrated that a number of challenges exist in the management of glare in construction work zones. One challenge is proper use of lighting equipment. The field experiments evaluated 25 typical lighting arrangements utilized by contractors. These experiments were conducted at the Illinois Center for Transportation (ICT), formerly known as ATREL.

The main lighting parameters that were evaluated included (1) the type of light equipment used, (2) luminaire mounting height, (3) luminaire aiming and rotation angles, and (4) height of vehicle and driver (El-Rayes et al. 2007). The results of this study were that (1) heights of lighting equipment should be set to the highest possible to reduce the resulting glare, (2) the aiming and rotation angles of light towers should be minimized and maintained around 0 degrees to reduce glare, (3) the maximum amount of glare was found to occur at a distance between 10 to 25 m before the light source, (4) a number of critical locations exist for lighting arrangements that have the maximum possible glare, (5) it is sufficient to make measurements of glare at its critical locations to judge on the suitability of the selected lighting design, and (6) balloon lights could still cause glare, but glare that is avoidable if they are mounted at 5 m or higher (El-Rayes et al. 2007).

A NYSDOT field study evaluated a semi-permanent lighting system for the illumination of construction work zones. This lighting system was composed of luminaires mounted on high-mast poles. The first use of this system was in 2005 on a three-mile stretch of I-90 at Albany, New York. The system was proposed as an alternative for portable light towers (Freyssinier et al. 2006). The measurements were made in conditions that had no ambient background lighting and followed IESNA measurement guidelines. The average illuminance was more than 100 lux, which is sufficient for the movement of construction workers and some construction activities, such as pavement resurfacing (Freyssinier et al. 2006). The results of the evaluation of the performance of the system, therefore, showed that it was able to meet lighting quality specifications for nighttime work zones. The comparison of the performance of high-mast lighting to portable light towers showed that it was able to provide sufficient illumination with few shadows and relatively-low glare.

2.5.3 Approaches

The lighting design models can be classified into three broad categories: (1) lighting calculation models, (2) lighting optimization models, and (3) lighting simulation models.

CONLIGHT was developed to quantify lighting quality based on different lighting design parameters. The development of this model was motivated by the difficulty of the lighting design calculation process. The model is a tool for contractors and agency engineers. The CONLIGHT model accepts lighting design parameters and produces the corresponding lighting quality parameter values. The model has three modules that quantified the average illuminance, the light uniformity, and the veiling illuminance (El-Rayes and Hyari 2005a).

The multi-objective lighting optimization models have been developed, which act as a search tool to identify optimal or near optimal lighting arrangements, while the CONLIGHT model is used to evaluate the fitness of the identified work-zone lighting designs. The main objectives of the multi-objective optimization models are to (1) maximize the average illluminance provided by the lighting design, (2) maximize lighting uniformity by minimizing the lighting uniformity ratio, (3) minimize glare by minimizing the veiling luminance ratio, and (4) minimize the cost of the lighting design by minimizing the total ownership and operating cost of the lighting equipment used.

Cost minimization is achieved by reducing the number of lighting units necessary to achieve an objective. However, the four objectives of the multi-objective optimization model were found to be conflicting in some regards. For example, the amount of average illuminance provided can increase the amount of glare produced by the lighting design. Therefore, to enable the simultaneous optimization objectives, a robust multi-objective genetic algorithm is used to fit lighting design solutions. This algorithm has the advantage of being able to produce multiple optimal solutions that created a Pareto optimal set of solutions. This produces a tradeoff between the multiple conflicting objectives of the work-zone lighting design problem (El-Rayes and Hyari 2005b).

Another type of work-zone lighting design model has been developed that attempts to simulate work-zone lighting arrangements. These models integrate three-dimensional lighting analysis software with discrete event simulation. The main advantage that this model has is that it uses a photometric web of light sources. By doing this, it can produce a more-accurate model of the impact of construction activities on work-zone lighting.

The model is also able to replicate the movement of construction equipment and workers in the work zone, something not previously considered in lighting design models. Such models offer the advantage of being able to represent traffic movement through the work zone using average daily traffic (ADT) data. This feature enhances the accuracy of the model, particularly in respect to the glare calculation. These models use dynamic and static lighting analyses iteratively with refinements introduced in each iteration until the set lighting criteria are met (Nassar 2008).

2.6 Productivity Impacts of Nighttime Construction

There is an intuitive correlation between nighttime work/shifts and losses in productivity. A number of studies have focused on productivity problems in construction, but no studies were found that directly concentrated on nighttime work productivity.

2.6.1 Problems

The impact of nighttime work on productivity has been the subject of several studies in the management domain (see Table 2.11).

Table 2.11. Productivity literature

	Authors											
Methodology and Findings	Arditi 1985	Thomas et al. 1986	Thomas, Yiakoumis 1987	Thomas et al. 1990	Motwani et al. 1995	Haas et al. 1998	Everett et al. 1998	Noor 1998	Abeid, Arditi 2002	Navon, Shpatnitsky 2005	Park et al. 2005	Lee et al. 2007
Method												
Survey	G				G						G	
Discussion									G			
Literature review				G	G			G			G	
Expert/focus groups											G	
Case studies						G	G					
Field measurements												
Statistical analysis			G			G						
Type of study		G				G						
Experiments/lab										G		G
Productivity data		G	G									G
Other data						G						
Findings												
Productivity improvement	G					G						G
Labor management	G	G						G				
Model development/		G	G	G	G				G	G		
Lessons learned							G					G
Productivity management techniques/system						G	G		G		G	G

N = Nighttime, G = General

Productivity has been defined as the output of a process related to the process inputs (usually the amount of time to complete a task) (Noor 1998). A number of studies have looked at the problem of nighttime construction productivity indirectly by examining the impact of shift work and overtime on productivity. Other studies considered the impact of nighttime work on human performance in general.

In general, contractors have three alternatives for accelerating construction projects: (1) extend working hours, (2) increase the size of the labor force, and (3) add a shift of workers. A large number of studies evaluated the effectiveness of overtime in accelerating construction schedules and its impact on labor productivity. However, very little research has been conducted on the effect of second shifts on the productivity of construction workers.

Hanna et al. (2008) used qualitative and quantitative analysis techniques to evaluate the impact of second shifts on productivity. The quantitative analysis quantified the impact of second-shift work on construction labor productivity. This analysis also examined the relationship between the length of the second-shift work and labor efficiency. Both analyses showed that second-shift work has the potential of being both beneficial and detrimental to labor productivity. If used judiciously in a well-organized manner, second-shift work can be a very effective method for construction schedule compression. The loss of productivity produced by the quantitative model ranged from -11 to 17 percent (Hanna et al. 2008).

The use of scheduled and occasional overtime has been frequent in the construction industry. Previous research has shown that using scheduled overtime continuously can negatively impact construction labor productivity. Sonmez (2007) focused on the evaluation of the impact of the practice of occasional overtime on construction labor productivity. That study collected productivity data for 234 weeks and quantitatively analyzed the data to determine the impact of occasional overtime. The quantitative analysis started with a t-test to evaluate the statistical significance of the impact of occasional overtime. The data showed there were deviations from the normal distribution in the data sample. Therefore, the data were analyzed using a Wilcoxon rank sum test, which showed that moderate use of occasional overtime did not lead to a significant impact on productivity (Sonmez 2007). These results indicated that occasional overtime is a better practice than scheduled overtime, given it may not impact labor productivity (Sonmez 2007).

A number of studies evaluated the impact of extended overtime on labor productivity. These studies showed that productivity decreases as the number of working hours per week increases. Hanna et al. (2005) focused on labor-intensive activities, such as electrical and mechanical work. However, little research was located that directly related to transportation projects. Overtime in this study was considered to be any work performed in addition to the typical 40 hours of scheduled work per week. In the study, data collected from 88 projects across the US were used to develop a model to evaluate the impact of extended overtime on the loss of construction productivity (Hanna et al. 2005).

The impact of nighttime construction activities on labor productivity may be associated with the circadian rhythm of human performance. This roughly 24 hour cyclic pattern has a number of biochemical, physiological, and behavioral manifestations that affect human performance. A number of studies have evaluated the impact of these rhythms on human performance.

One of these studies analyzed the variations of human time estimation performance during periods of sleep deprivation (Miro et al. 2003). The study was performed on 30 participants between the ages of 18 and 24. The subjects were required to perform time estimates of 10 second intervals. The results showed that the time estimation lengthening was modulated by circadian oscillations. No differences were observed due to the gender of the subject. Variations in time estimates were found to be correlated significantly with body temperature, skin resistance level, and the sleep deprivation period.

When sleepiness increased, time estimation was found to be lengthened, and the opposite was also found to be true. The reason the lengthening of time estimation is important is that many tasks and situations (especially in nighttime construction operations) require time estimation under moderate or severe sleep loss, which is a significant factor in both the efficiency and safety of labor (Miro et al. 2003).

Another study that evaluated the impact of circadian patterns asked subjects to perform a range of tasks every two hours to estimate the magnitude of the endogenous and exogenous components of the subject's circadian pattern. Performance during the different phases of the circadian cycle was found to be considerably different with respect to the different tasks performed (Folkard et al. 1993). The results indicate that performance on tasks may adjust at varying rates, which means that shift timing and operations may need to be adjusted according to the type of work tasks (Folkard et al. 1993).

To illustrate the difference between the circadian rhythms of different subjects with different levels of physical activity, a study evaluated these rhythms for a group of male subjects between the ages of 19 and 29. The subjects were first divided into two groups: physically active and physically inactive. A number of measurements were made on these two groups every four hours, including body temperature, resting pulse rate, and subjective arousal and sleepiness. In addition, a number of tests were performed in eight-hour intervals, including whole-body flexibility, back and leg strength, grip strength, flight time for a vertical jump, and self-chosen work-rate. The subjects were asked to avoid exercise 48 hours before the tests. The results demonstrated that the physically active group was 1.5 to 2.5 higher in the amplitude of their rhythms than the inactive group for a number of tests, including body temperature, subjective arousal and sleepiness, flexibility, grip strength, sub-maximal heart rate, and self-chosen work-rate. The phases of the rhythms did not differ for the two groups, but early morning troughs were higher for the physically active group (Atkinson et al. 1993).

Horne et al. (1980) conducted a study to evaluate the impact of circadian rhythms on subjects who have a preference for working in the morning and subjects who have a preference for working in the evening. The study focused on the performance efficiency of workers in a simulated product-line inspection task. The study used 15 sessions at different times of the day over several days. The results showed there were no significant changes in circadian trends between and within groups in the number of wrongly-rejected items. There were significant differences, on the other hand, in the number of correctly-rejected items between morning-preferring subjects and evening-preferring subjects in the morning. The morning subjects were able to reject more items correctly in the morning than evening people. The subjects preferring to work in the evening showed a steady improvement during the day, while the performance of morning-preferring subjects declined. The performance of morning-preferring subjects declined suddenly right after lunch, while the performance of evening-preferring subjects did not show such a decline.

Alertness of humans as measured by the EEG measure showed a strong circadian rhythm with the least alertness occurring between 1:00 a.m. and 6:00 a.m., which coincides with night-shift work. A number of studies illustrated that performance in monotonous tasks requiring vigilance declines when alertness is reduced. Therefore, this is an important consideration in designing process-control human-machine interfaces.

In this design process, there is a concern that the increased automation and reliability increases the risk of operator error due to monotony, especially during night shifts. To evaluate the impact of nighttime work on operator performance in industrial process-control consoles, a study was conducted with a group of volunteers working 12 and eight-hour night shifts in a simulated industrial control room. EEG was measured for all subjects going through testing to determine subject alertness (Moore-Ede et al. 1989).

One of the main factors influencing circadian rhythm phase in performance efficiency is the memory load involved in the task. To determine the impact of memory load on the rate at which rhythms adapt to phase-shifts, two experiments were conducted to evaluate subject performance in trans-meridian flight and for long-period night work. The first experiment was conducted on a 25-year-old female subject who experienced a five-hour eastward change in time-zone. Two versions of the test were conducted, a low- and high-memory version. The results showed a difference in the initial phases of the two tests and in the rate at which these phases adapted to the new time.

The second study had two male subjects who worked 21 consecutive nighttime shifts. These male subjects were also subjected to a high- and low-memory-load version of the performance test. The men were also subjected to a calculations test every four hours. The results of the second study were similar to the first study; however, the second study showed that differences in the rate of adaptation of phases of performance rhythms exist between the low- and high-memory-load versions of the test. The second study also showed a difference between temperature rhythm and performance. The study demonstrated it is not very accurate to utilize a single performance test in determining shiftwork and jet-lag effects; instead, the performance test should simulate, to some extent, the task being performed (Monk et al. 1978).

These studies illustrate that productivity in nighttime construction operations is affected by circadian patterns and, therefore, there is a need to schedule different types of nighttime construction activities carefully. Unfortunately, the literature is very sparse in directly addressing nighttime construction activities.

2.6.2 Study Methods

Construction productivity, in general, has been the subject of many studies aimed at developing accurate methods for productivity measurement, modeling, and improvement. Although the studies did not focus on nighttime construction productivity in particular, the methodologies developed are still very relevant to nighttime construction. Therefore, a summary of a number of these studies is relevant to the current research.

The focus of many construction-improvement programs is the acquisition of accurate and consistent labor productivity data. The quality of the data collected by these exercises usually depends on the collection effort. There are also many sources for this data, including historical site records and productivity studies conducted using multiple methodologies. The problem is that most of these methods suffer from a lack of consistency in the way they are performed. Therefore, Noor (1998) critiqued and analyzed existing productivity measurement methods to develop practical and cost-effective productivity data collection methods that lead to consistent and accurate productivity information.

The main focus of labor productivity measurement methods is to determine the input times (amount of time needed) for each type of work. The observations made of these input times could be either continuous or discrete at intermittent intervals. The main tradeoff between these two types of observation techniques is in the amount of time needed to make the observations versus the accuracy of the data collected. A number of productivity measurement techniques are documented in the literature: direct observation, work study, audio-visual, and activity sampling (Noor 1998).

Building on past studies, Noor (1998) suggested a number of requirements for productivity measurement methods, including (1) method should allow for monitoring multiple trades simultaneously on site, (2) the cost of the method should be reasonable to allow for frequent collection of data, (3) the method must be able to accurately measure inputs and outputs of the process monitored, and (4) the method should not be time consuming. These proposed requirements make many common productivity-measurement methods less than optimum on construction projects (Noor 1998). Therefore, a number of studies have sought to use innovative technologies for construction productivity measurement.

One of the leading studies that proposed the use of advanced technologies for real-time construction monitoring was by Navon and Shpatnitsky (2005). This study used a global positioning system (GPS) for on-site automated data collection. The GPS was used to monitor the position of earthmoving equipment on a road construction project continuously. The prototype model was able to measure the position of earthmoving equipment at regular intervals, and, then, use these locations to calculate the equipment productivity. The conversion of this location information to productivity took place by associating location information with work envelops. Locations not associated with work envelops were associated with work sections, based on logical decision rules.

The developed construction monitoring model was tested and validated on-site in a number of field experiments. The results of these field studies illustrated that the model was able to achieve an accuracy of ±4 to 5 percent for unstructured activities. The achieved accuracy was even higher for more-structured activities, such asphalt spreading. However, the model was not always reliable. It had the potential of failing in cases due to the nature of GPS communication systems. The first case is when the equipment is operating in areas close to bridges and/or retaining walls. This may cause the model to miss a number of readings. The second case is when equipment has to move long distances to load or dump material, which makes the equipment not fit within any defined work envelop (Navon and Shpatnitsky 2005).

Advances in computer graphics and image processing have led to the development of innovative methodologies for monitoring construction activities. These methods use software capable of generating time-lapse playbacks of the needed frame rate from digital videos recorded on the construction site. One of the problems resolved by the system is the storing of the vast amount of data generated (Abeid and Arditi 2002). The results of the deployment of the system showed that the optimal frame rate for recording construction operations was 60 frames per minute. At this rate, it was possible to conduct accident analyses that take only a few seconds to occur. The system solves the data storage problem associated with the large number of frames needed to monitor project information, by compressing the frame images by 80 percent using the JPEG format (Abeid and Arditi 2002). (JPEG is an acronym for the Joint Photographic Experts Group, which created this standard file compression format.)

Another variation of time-lapse photography is time-lapse video recording. This method has the advantage of allowing lengthy construction processes to be recorded and viewed in a shorter amount of time. This method is considered an extension of time-lapse photography, and was used by Everett et al. (1998) to monitor entire construction projects, instead of monitoring individual crews or laborers. The recorded video can be used for progress documentation, operations analysis and improvement, public relations, and dispute resolution.

The method was applied at a number of projects over several years (Everett et al. 1998). The findings showed that this tool could be of benefit in documenting actual project progress. The videos produced were used for resolving claims and disputes in a number of projects. The videos were also used to assist project managers in managing projects remotely. The setup cost of the time-lapse video system is relatively low and the installation and operation is easy, which encouraged the University of Michigan to apply this method on 11 university projects (Everett et al. 1998).

The data from the productivity measurement techniques discussed in the literature has been utilized in a number of efforts to create models that predict construction productivity. Thomas and Yiakoumis (1987) developed a factor model for predicting the productivity of labor-intensive construction activities. The model utilizes a number of factors that may disrupt crew performance and quantifies the impact of these factors to discount them from productivity data, producing an ideal productivity curve, which can be used for forecasting productivity performance in the future.

The model was based on data collected from three commercial construction projects. The validity of the model was checked by considering the impact of temperature and relative humidity on productivity. The data was then analyzed using multiple regression methods. It was able to explain 40 percent of the variation in daily productivity data. The model also included a number of other statistical factors. The results of the developed model were compared to those of similar models in the literature. The comparison showed that the model was consistent with the models described in the literature. In addition, the validity of the model was evidenced by the low variability displayed by the productivity curve compared to the original productivity data. An added advantage of the model is that it could be further enhanced by additional projects, which could be added to its database (Thomas and Yiakoumis 1987).

Another study that attempted to offer a model of labor productivity used a theory called short run marginal productivity (SRMP). This theory has been used by economists as an explanation for employment productivity and efficiency. The study, therefore, utilized SRMP and shift records to investigate if there are any consistent productivity differences between different shifts at different times of the day.

The records were collected from five manufacturing plants, and for each plant, the capital stock (which indicates the amount of machinery and investments) was similar. The output of the production process was a homogenous product and wages during different shifts was known. The reason this was important was that some researchers argued that higher wage shifts have higher levels of marginal products and others have argued that changes in productivity are related to changes in capital stock (Boddy et al. 1986).

The results of the analysis demonstrated that in some instances there is no systematic relationship between wages and labor productivity, as predicted by the SRMP theory. Another important finding was that wages are related to productivity in the regular shifts, but not during overtime periods. The study demonstrated that, given a fixed crew size, productivity is more a function of downtime rather than relative wages. The third important finding of this study was that extreme variations exist in productivity, even during days that had a fixed wage rate (Boddy et al. 1986).

Productivity modeling has long been performed in the manufacturing industry. One of the techniques developed in the manufacturing industry was work-study modeling. These models represent the delays, activities, and tasks in models (Thomas et al. 1990). Research has demonstrated that these models are not always adequate and reliable for construction productivity. The reason these models did not have the needed reliability is that they focused on work methods, while productivity improvement in construction can also be achieved by focusing on factors outside the control of management, such as economic, union, and public factors.

Thomas et al. (1990), thereby, created two reliable productivity models that were validated specifically for construction situations. These models are based on the project, site, and management factors that affect project productivity, as well as the motivation-expectancy mode, which models how crews exert efforts and how effort relates to productivity (Thomas et al. 1990).

The third type of construction productivity model is based on the learning-curve effect. Thomas et al. (1986) created five mathematical learning-curve models. The models determined the correlation between predicted and actual unit rates. This analysis illustrated that the best predictor of this correlation is a cubic model and not the straight-line models often cited in the literature. This inadequacy was further highlighted by results showing the learning rate was not a constant value. The model was developed using data from building projects (specifically, the task of erecting and setting precast concrete floor planks) (Thomas et al. 1986).

One other study was found that investigated productivity in construction projects, by Haas et al. (1998). The study analyzed trends in construction productivity over the past 25 to 30 years. The study specifically aimed at the evaluation of trends against a set of benchmark values of productivity, rather than the absolute value of productivity. The methodology followed in the study relied on the unit labor cost and unit output published in the Means Building Construction Cost Data. This publication is used as a guide by many for cost-estimating purposes. The unit labor cost values provide a measure of productivity as it relates to capital resources, while unit output figures provide an indication of the efficiency of labor used on the jobsite (Haas et al. 1998).

The approach for evaluating long-term labor productivity trends had two main stages. The first stage selected a number of representative tasks to be measured and tracked. These included: soil compaction, trenching, pipe installation, accoustic ceiling installation, wall framing, and open-web joist installation. Each of these activities were selected because they represent a different level of technology or an important segment of the consruction industy (Haas et al. 1998).

The second stage of the study looked at a series of work-sampling studies to determine work rates for different activities. A 25-year-long work study of 72 projects in the Austin, Texas area provided the work rates (which is a measure of the efficiency of work being performed by labor). The results of this study indicated that construction productivity had risen during the two decades prior to the study, due to depressed labor wage rates and advances in construction technology, but management practices were a major driver in productivity improvement (Haas et al. 1998).

2.6.3 Approaches

Unlike construction productivity measurement and modeling efforts, productivity-improvement studies aim at offering solutions to the persistent productivity problems of the construction industry. Arditi’s (1985) study aimed at solutions. He sought to obtain the views of contractors about where productivity improvements would be most effective. The information was compared to similar work conducted in 1979. The results indicated the industry believes the critical areas for productivity improvements are planning and scheduling, labor-management relations, site supervision, industrialized building systems, equipment policy, and engineering design.

The California Department of Transportation (Caltrans) has been experimenting with long-life urban freeway rehabilitation projects that used around-the-clock construction operation for minimizing the impact on motorists. These projects have provided data to evaluate as-built productivity rates (Lee et al. 2007). The productivity rate study investigated projects that employed different lane closure schemes and different rehabilitation strategies. The results showed that production rates and learning-curve effect were higher in cases where the roadbed was fully closed and full lane widths rehabilitated, compared to cases of partial closure and partial-width rehabilitation. It was noticed that continuous slab replacement had a higher production rate and learning-curve effect than random slab replacements. These results imply that lane closure schemes affect productivity (Lee et al. 2007). The study findings were, however, unable to discern affirmatively the impact of nighttime activities alone (as compared to extended closure schedules) on construction operations and traffic delays (Lee et al. 2007).

Park et al. (2005) focused on the development of a consistent and common set of productivity metrics for the construction industry in general. This study aimed at creating a Construction Productivity Metrics System (CPMS) that contained a list of accounts and project data elements grouped into seven major categories. The CPMS was created as a standard productivity data collection tool with the help of 73 industry experts who determined the needed data elements. The CPMS tool was initially tested on 16 industrial construction projects, and the results demonstrated the feasibility of collecting the data required by the system. The results also showed that the system is a meaningful tool for construction productivity benchmarking. The relatively small sample size, though, prevented the study from having more-specific conclusions (Park et al. 2005).

2.7 Work-Zone Planning Risk Analysis

On average, there are 900 fatalities per year in roadway work zones in the US. In Iowa, there are an average 6.5 deaths and 366 work-zone crashes per year (Iowa DOT 2008). Typical initiatives to reduce these numbers are physical in nature and are put in place at the work zone during construction.

2.7.1 Problems

Risks in construction work zones are numerous. Risks include vehicle intrusions into the work zone, resulting in workers being struck by intruding vehicles; workers struck by construction equipment; and construction equipment intrusion in operational traffic lanes. Measures to reduce these risks include increased fines for moving traffic violations occurring in work zones, transverse rumble strips, reduced spacing for channelizing devices, enhanced flagger station setups, reduced work-zone speed limits, and variable message signs. However, physical traffic-calming measures have not always proven to be effective when not followed up with enforcement.

Enforcement places a significant burden on law officials, and positioning law enforcement officers and vehicles within the work zone can create hazards for both enforcement officers and highway workers. It may be more effective and efficient to use innovative contracting and the project administration process to address work-zone safety. Contracting and administrative risk-reduction efforts must begin during project planning and continue through the design and preconstruction phases of the project.

Most of the literature focuses on the traffic-control plan for nighttime construction projects, with some providing guidelines and specifications for managing construction work zones during nighttime work. Different methodologies have been used to conduct the studies and the research provides distinctive findings for enhancement measures to reduce risk in construction work zones.

2.7.2 Study Methods

Different methodologies have been used by researchers in studying risk and construction work-zone risk and accidents (see Table 2.12). Participants in surveys have included STA staff, owners, contractors, construction workers, and the traveling public.

Akintoye and MacLeod (1997) used a questionnaire survey to ascertain the construction industry's perception of risk associated with activities and the extent to which the industry uses risk analysis and management techniques. The development of the questionnaires resulted from discussions with an advisory group formed by the researchers (Holguin-Veras et al. 2003).

Other methodologies adopted by the researchers include interviews, site visits, and observations. Researchers favor interviews as a way to gather in-depth information on a certain issue. Holguin-Veras et al. (2003) used interviews to examine the impacts that nighttime construction activity has on workers, from their perspective. Most of the interviews were with construction, engineering, procurement, and quality personnel, from various owner and contractor firms involved primarily in heavy industrial, manufacturing, and commercial construction.

Field measurement during site visits has been used by some researchers. Cottrell (1999) conducted on-site visits to seven nighttime work zones to observe and identify specific problems encountered with traffic control for night work.

Other methods of data collection include videotaping, study of crash records, and simulation. Crash data includes information involving the traveling public. The data from various agencies have been used to determine the impact of the nighttime work zone on the number of accidents experienced by the traveling public. The data includes accident reports from police, highway patrol, and STA sources. Information was also obtained for non-work-zone areas to establish a normal level of crashes.

Table 2.12. Risk/work zone literature

Methodology and Solutions	**Authors**							
	Akintoye, MacLeod 1997	Cottrell 1999	Holguin-Veras et al. 2003	Bryden, Mace 2002a	Ullman et al. 2006	McAvoy et al. 2007	Ruyle 2007	Wayne State, Bradley 2007
Research Method								
Survey	G	N	N					N
Literature review		N		N			N	N
Interviews		N	N					N
Field measurements								
Simulation						N		
Type of study						N		
Modeling								
Observation/visit		N	N		N			N
Data set					N			
Videotaping			N					
Crash records					N			
Solutions								
Risk strategies/methods/programs	G			N				
Work-zone speed/crashes					N	N		
Guidelines/spec		N					N	N
Traffic control plan		N		N	N	N	N	
Temporary devices				N		N		
Human factors			N					

N = Nighttime, G = General

2.7.3 Approaches

A number of options have been explored to address work-zone risk. These include developing guidelines and specifications related to construction work zones, addressing proper traffic-control planning, temporary devices, and applying risk-management strategies, methods, and programs. However, developing guidelines and specifications related to construction work zones are the most often discussed solutions. Traffic control plans and speed control have been studied for the safety of the worker, as well as for the safety of the traveling public.

The guidelines developed throughout the studies cover different aspects of work-zone issues, from traffic-control plans to safety in the work-zone area. Guidelines by Bryden and Mace (2002a and 2000b) addressed the nighttime safety concerns and methods of traffic control, aside from illumination requirements.

Most of the studies in the risk and work-zone area emphasize the importance of having proper traffic-control plans when conducting nighttime construction activities. Bryden and Mace (2002a) emphasized traffic-control devices and safety features such as changeable message signs, flashing-arrow panels, temporary signals, traffic barriers, arrestor nets, and intrusion alarms.

Enhancing traffic controls helps in reducing accident risks. Physical control methods include using truck-mounted impact attenuators, to reduce the severity of a collision with a shadow vehicle, and buffer lanes between the open lane and the lane where the work is occurring (Cottrell 1999).

Risk-management programs should be implemented to improve safety in construction work zones. According to Akintoye and MacLeod (1997), the construction industry has approached risk management in terms of individual intuition, judgment, and experience gained from previous contracts. Therefore, it is essential to ensure that the construction personnel and management undergo training on risk-analysis assessment to help them formalize their judgments about project risk in a more precise way.

2.8 Nighttime Construction Cost Differentials

Project cost is always a great concern for transportation agencies. There are a number of factors which impact cost throughout the lifecycle of a project (Shane et al. 2009). With the addition of equipment, such as lighting, and the deviation from normal work hours, construction at night has an impact on the cost of construction. However, construction cost is only one component of the cost of a project; other costs, such as user and design costs, may be impacted differently than construction cost.

2.8.1 Problems

In a number of studies, the cost of construction has been shown to be impacted by scheduling nighttime construction operations (Kumar and Ellis 1994). Methods for obtaining information on cost differentials in construction have been studied by a number of researchers (see Table 2.13).

Most of the literature reports on construction costs, in general, rather than on nighttime costs, specifically. Different types of methodologies have been applied in the studies and provide unique findings pertaining to construction cost in general.

Table 2.13. Cost differential literature

	Authors				
Methodology and Solutions	Kumar, Ellis 1994	Okpala, Aniekwu. 1998	Akintoye 2000	Al-Kaisy, Nassar 2009	Zhu et al. 2009
Research Method					
Surveys		G	G		G
Framework				N	
Field measurements					
Data set	N				G
Modeling				N	G
Case studies					G
Solutions					
Development of system /tool/model				N	G
Cost-effectiveness analysis				N	
Cost comparison	N				G
Construction industry		G	G		

N = Nighttime, G = General

2.8.2 Study Methods

Different types of methodologies have been used to conduct daytime versus nighttime cost differential studies. Field measurement was the most often used method discussed in the literature. Different types of field measurement data have been used forecasting cost models (Al-Kaisy and Nassar 2009). Modeling has been used to analyze and make comparisons between daytime and nighttime operations.

Some of the studies conducted used data sets for analysis purposes. Further analysis on particular sets of data have been performed to examine cost components associated with nighttime construction, including project costs and user cost savings to the traveling public (Kumar and Ellis 1994). In addition, empirical data specific to a certain location was used in a road user cost calculation procedure (Zhu et al. 2009).

Surveys are another tool widely used to gather construction cost information. Most of the surveys were distributed to people in the construction industry, such as engineers, architects, quantity surveyors, and contractors. Akintoye (2000) designed a survey incorporating factors causing delays and cost overruns, whereas Zhu et al.(2009) used two surveys to support the current road user cost calculation methods used by FDOT district engineers.

2.8.3 Approaches

Options explored by researchers in addressing the cost-differential issues include development of decision tools or models. Al-Kaisy and Nassar (2009) proposed a decision-support tool applicable to situations when night shifts are thought of as an alternative to conventional daytime shifts in highway projects on freeways and multilane highways. The tool could be used to evaluate various lane-closure strategies or the use of work shifts during weekends.

Okpala and Aniekwu (1998) and Akintoye (2000) both conducted studies to determine the factors influencing project cost. An initial analysis of the factors studied shows that the main factors influencing cost are complexity of the project, market condition, method of construction, site constraints, client’s financial position, project buildability, and location.

Two researchers, Kumar and Ellis (1994), provide a cost comparison of nighttime construction that is really a look at user-cost consequences. According to this study, nighttime work is economically beneficial on urban highways, given greater daytime traffic than that experienced at night.

Studies demonstrate that a number of cost components are impacted, including direct construction cost and accident costs.

2.9 Literature Review Conclusions

The literature review reveals that agencies and researchers are concerned with all aspects of the research, and most-notably safety and illumination. There were, however, gaps in the information available, particularly in the cost differentials and in risk. The literature review also indicates that several of the research aspects are more holistic to the project process, and not limited to only nighttime issues: these areas are quality, productivity, communications, and nuisances. The literature review did not uncover a comprehensive source for nighttime construction. Therefore, the development of the Guidebook as part of this project was an appropriate objective.

The information found through the literature is one source of information for the Guidebook. The literature and gaps in information served as one point of development for the additional information gathered in Phase II.

CHAPTER 3: PHASE I SURVEYS

The main objectives of the Phase I questionnaires were to (1) collect information from the agencies regarding their use of nighttime construction, (2) identify contacts in the agencies that may possibly be used for the Phase II case studies, and (3) compile comprehensive guidelines of the best practices for nighttime highway construction and maintenance operations. To do this, a set of surveys were developed, based on the literature review and the objectives of this research.

3.1 Methodology

To achieve the research objectives, a survey, seeking information about different aspects of nighttime work, was addressed to the 50 STAs. This agency survey was divided into the following sections:

1. General organization information
2. Quality
3. Safety
4. Nuisance
5. Communications
6. Illumination
7. Construction productivity
8. Risk
9. Cost

The first item covered a more global, organizational perspective; therefore, that section of the survey was addressed in a separate survey (Survey 1), in which organization management was the targeted respondent. The other nine sections were addressed in a second round of surveys (Survey 2), in which district personnel or project managers with hands-on nighttime construction experience were targeted.

Phase I Survey 1

The first survey distributed was general in nature and asked respondents about the use of nighttime construction techniques in their specific agency, when and who makes the decision to use nighttime construction, and who to contact for the second round of surveys (see Appendix A). This first survey was distributed to the Transportation Research Board (TRB) representative for each STA and to the members of the American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Construction.

An email message was sent to each TRB representative and, attached to the message, was a letter describing the project and the survey objectives. The email message stated the purpose of the project and directed recipients to the letter for additional information.

The email message also asked recipients to either complete the survey using the online survey tool Zoomerang™, via the provided link, or to complete the attached version and submit the information by either fax or email. A suggestion was made that the respondent might want to look at the attached survey prior to visiting the Zoomerang site to ensure they had all of the information requested, given a response through Zoomerang cannot be saved and revisited for completion.

Respondents were asked to complete the survey in one week. Part way through the week, an attempt was made to contact the respondents who had not completed the survey. These contacts were made via phone. The person calling asked if the respondent had any questions regarding the survey and when the respondent planned to complete the survey. If the respondent could not be reached, the caller left a message and attempted contact at a later date.

Phase I Survey 2

The respondents to the second Phase I survey were identified in the first Phase I survey.

The second Phase I survey was composed of multiple questionnaires (see Appendices B through J). The questionnaires in Appendices C through J were sets of questions directly related to the individual areas of interest related to this study. Respondents were asked to complete only one questionnaire of this series—the one for which they had knowledge. The questionnaire in Appendix B sought more general information about each agency.

Distribution of this round was similar to that of Phase I Survey 1. An email message was sent to respondents with two attachments: a cover letter and the questionnaire. Similar directions were given to respondents regarding reading the letter and looking at the questionnaire prior to using the Zoomerang link. This was critical in this step, as more-specific information was requested.

The goal of this survey round was to gather specific information regarding the agency's experience with specific areas of interest to this research. The respondents were asked about the impact that nighttime construction has on the research areas of interest, for specific policies and procedures used by the agency, and if there were any innovations that have been witnessed and could be reported.

Developing definitive information about the impact nighttime construction has had on the area of interest as seen by the agency permitted general information to be collected by the researchers in all areas of interest and provided useful information for the project deliverables.

Requesting specific policies and procedures allowed the researchers to build a library of useful information. This information was compared between states and different practices identified in the Guidebook. These were used to build a toolbox of practices and should enable agencies to find information about what other agencies are doing.

Examining the policies and procedures, along with collecting information about innovation in a specific area, enabled the researchers to have a better understanding of agency experience in the various areas of this research. The researchers used this information in the selection of case studies. Knowing which agencies have experience with innovative practices provided the research team with information to explore in Phase II of the project.

3.2 Phase I Survey Results

The research team began distributing the first survey on August 18, 2009. As previously noted, the survey was sent to members of the TRB and the AASHTO Subcommittee on Construction. Thirty-two states responded. Figure 3.1 depicts responses to this survey by the presence of a pie graph on the map.

Responses were also received from the Federal Highway Administration (FHWA) and three Canadian provinces. The responses are geographically dispersed and represent a number of different types of programs. The research team phoned agencies that had not responded and continued to encourage them to respond.

On August 31, 2009, the research team deployed the second round of surveys to the agencies that had completed the first survey. As previously noted, the second-round survey consisted of several different surveys, with one for each specific area of interest, such as communications, cost, illumination, and so on, as well as a general survey. Respondents were sent a link to only the portion of the questionnaire for which they had been recommended, plus the general portion.

Responses to portions are indicated by the color-coded portions of the pie graphs in Figure 3.1. The various portions are represented by a specific color and pie piece. For example, communication is blue and is the piece of the pie in the 12 o'clock to 1:30 position. Likewise, the quality portion is orange and is in the 6:30 to 7:30 position of the pie.

Eight states completed all of the surveys. Given this limited response rate, there are limited analyses and findings to support some areas of the project.

Thirty-nine responses were obtained to the initial survey. Of these responses, 38 indicated that the agency conducted nighttime construction. The decision to use nighttime construction could be made throughout the project life cycle, with the decision usually being made during advance planning and preliminary design, according to 31 respondents (see Figure 3.2). This decision is made at different levels in many agencies; therefore, different people may be involved (Figure 3.3).

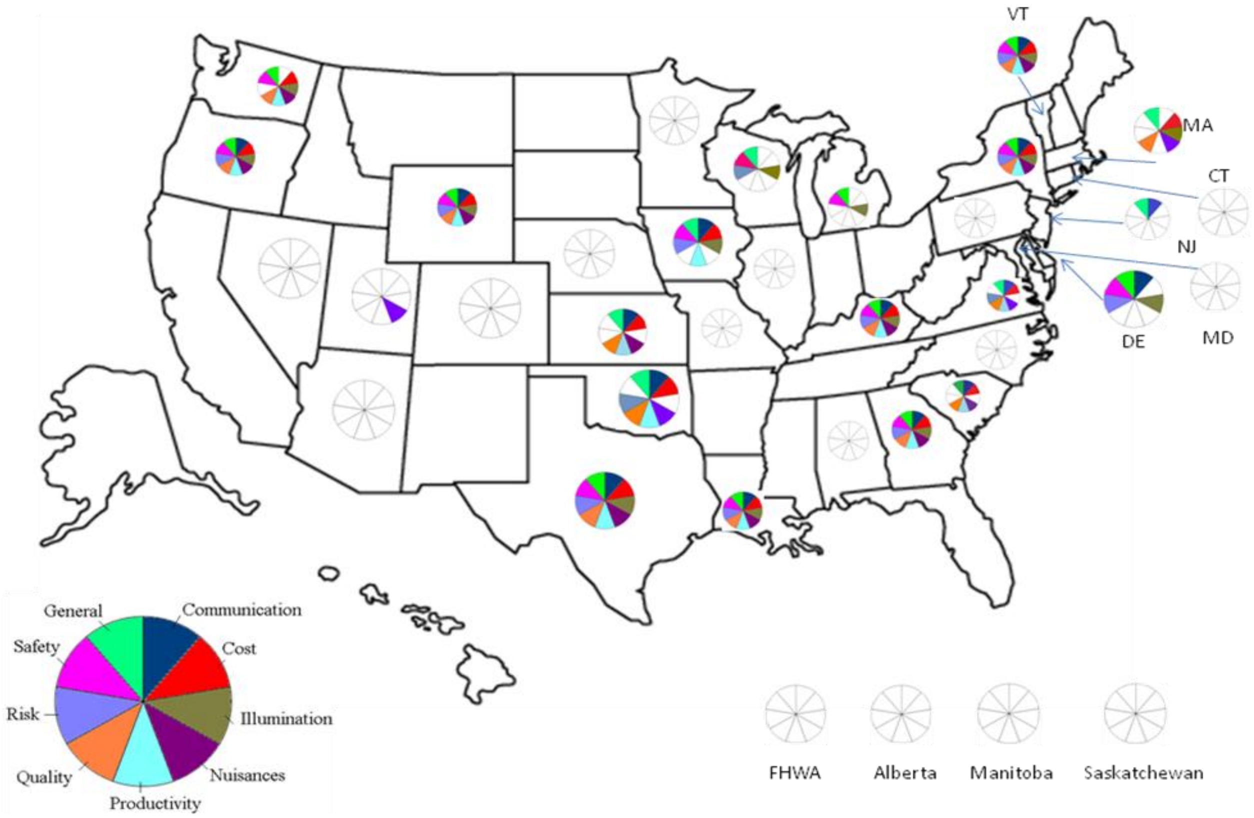


Figure 3.1. Responses to questionnaires

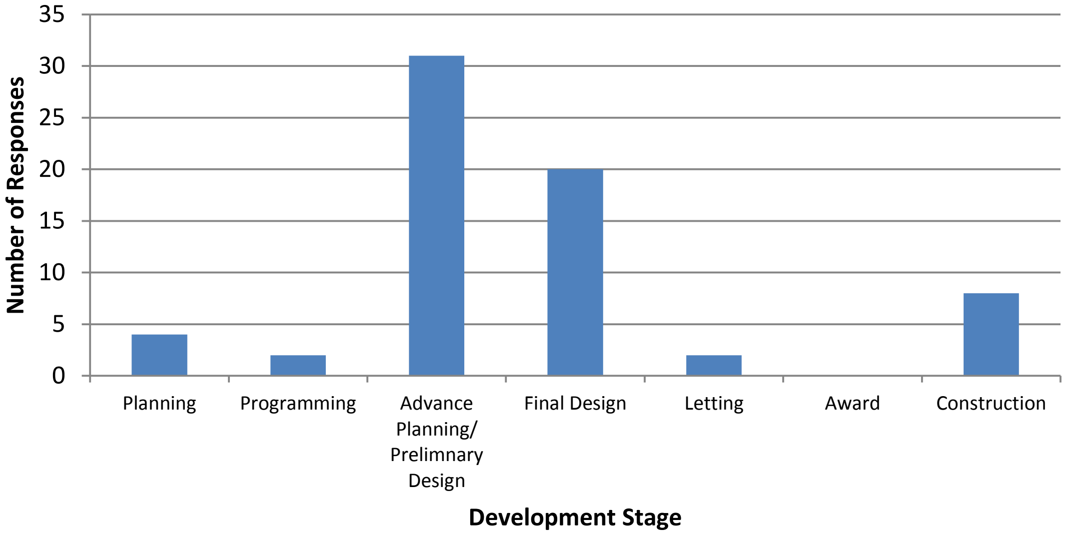


Figure 3.2. Project development phase at which decision to use nighttime construction is made

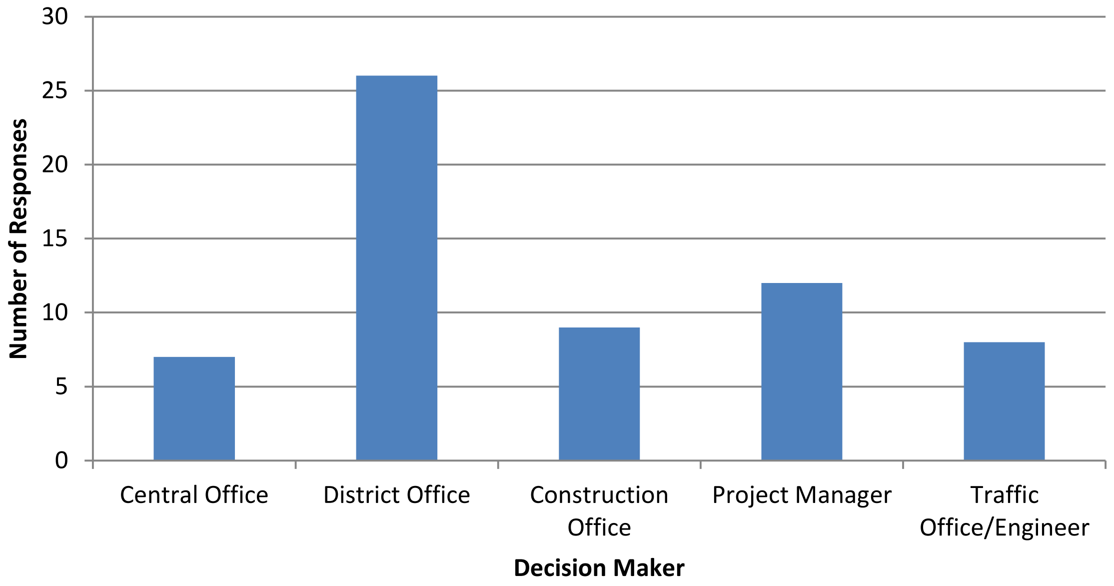


Figure 3.3. Decision maker for use of nighttime work

When asked about the factors that affect the choice of completing activities at night, congestion is the primary reason, with 36 positive responses and no negative response (Figure 3.4). Other highly-rated factors include safety, traffic control, public relations, user cost, and scheduling. User cost is one of the most highly rated decision drivers. While other costs are not as important, construction cost is considered by 19 respondents. Maintenance and accident costs are considered by fewer respondents.

The first survey asked about activities commonly-conducted by agencies during nighttime hours. The survey instrument specifically listed 29 different maintenance tasks and asked for comments. Repair of concrete pavement; resurfacing, milling, and removal were reported as common nighttime activities, engaged in by 18 of the responding agencies (86 percent). Among the common activities listed, no agency reported performing riprap maintenance or landscaping/grading/sodding activities at night. One agency indicated that the type of maintenance work performed at night depends on work location, and one respondent reported doing overhead signing work at night.

Twenty-one respondents stated that their agency has guidelines or specification for performing nighttime construction, while 17 do not. Of the agencies with guidelines or specifications for performing nighttime construction, nine of them are different from daytime specifications. Links too many of these specifications were provided by the respondents. (References to specifications or guidelines provided by respondents throughout the survey process are in Appendix K.)

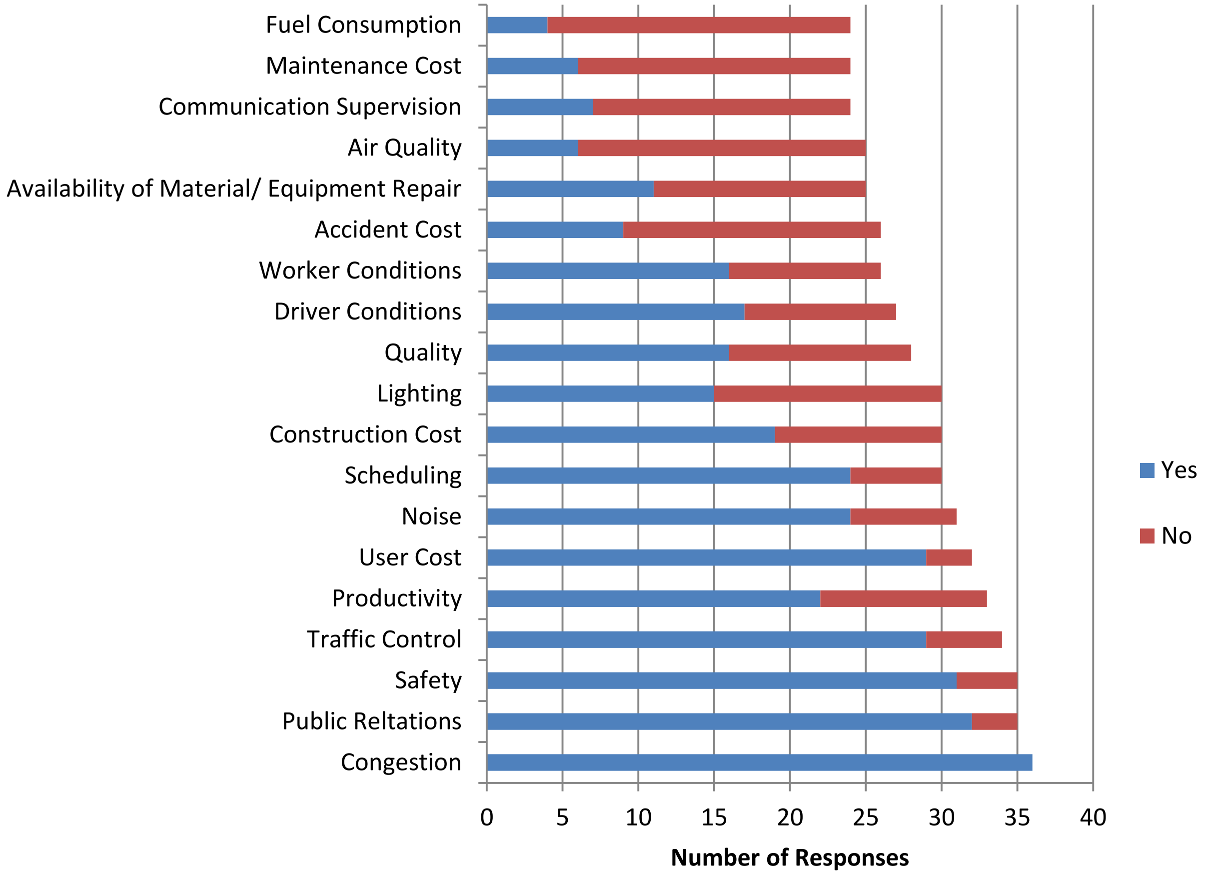


Figure 3.4. Factors that affect choice of using nighttime construction

3.3 Phase I Survey 2 Results

The second survey consisted of nine individual survey forms. These forms were each emailed to the individual contacts obtained from Phase I Survey 1. Eight of the nine surveys in this round covered the eight individual aspects of interest. The ninth (and initial) survey was general and was sent to all of the contacts obtained in Phase I Survey 1.

3.3.1 Phase I Survey 2 – General

There were 21 respondents from different STAs and other agencies that answered the survey regarding the general aspect of nighttime construction. Problems associated with a construction night schedule were identified by 17 of the respondents.

Ten respondents (48 percent) stated that lighting contributes significantly to problems during nighttime operations (Figure 3.5). Factors that moderately cause problems are quality (12), followed by productivity (11).

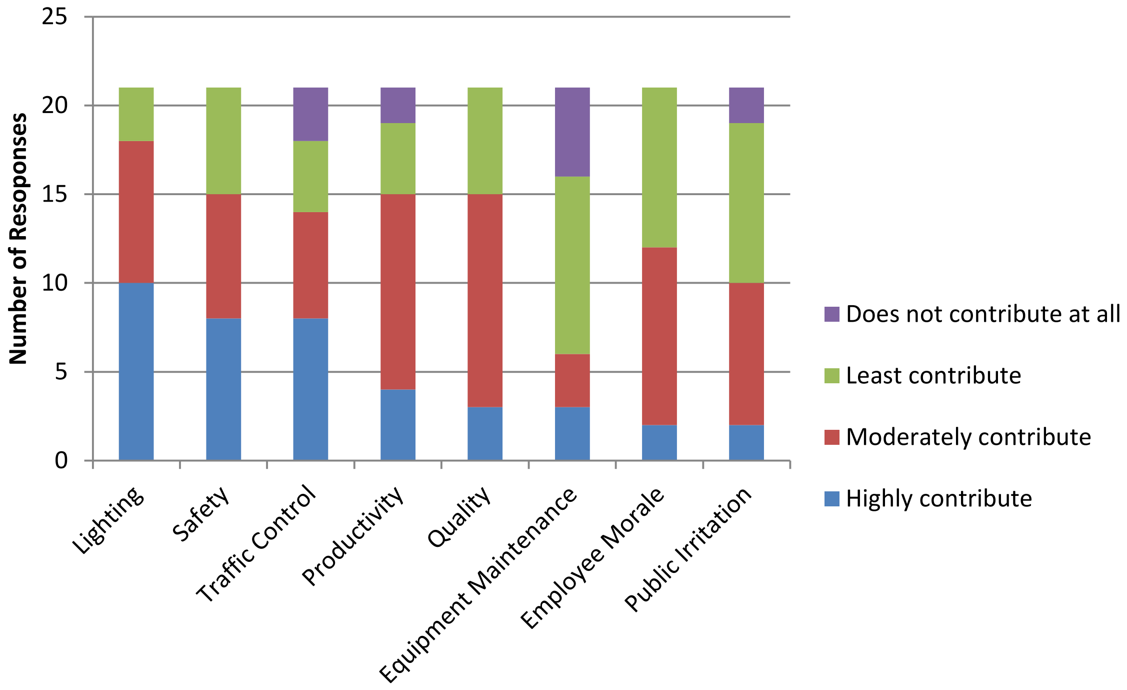


Figure 3.5. General areas that contribute to nighttime construction problems

Equipment maintenance, employee morale, and public irritation are the least problem contributors. Three respondents indicated that tired employees and the difficulty of finding and having access to supply materials can be problems associated with nighttime construction.

Thirteen respondents agreed that less delay and congestion is the most important advantage of nighttime operations (Figure 3.6). In contrast, 10 respondents reported that less air pollution is the least important advantage. Moreover, 12 respondents considered reduced impact on surrounding business as a very important advantage of nighttime construction.

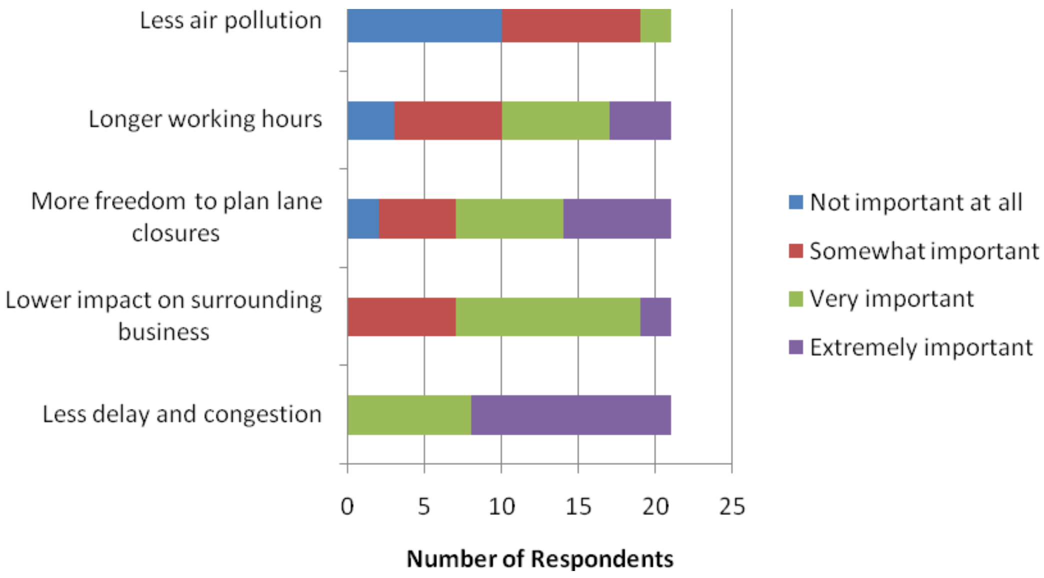


Figure 3.6. Respondent opinions on the advantages of performing nighttime work

Among the disadvantages listed, respondents agreed that visibility problems and higher worker accident rates are the main difficulties experienced when performing nighttime work, (Figure 3.7). Alternately, equipment maintenance problems were reported as the least important disadvantage. Noise, decreased productivity, and material availability problems are the disadvantages that were thought of as somewhat important when considering nighttime construction. Another disadvantage that is considered important is worker safety.

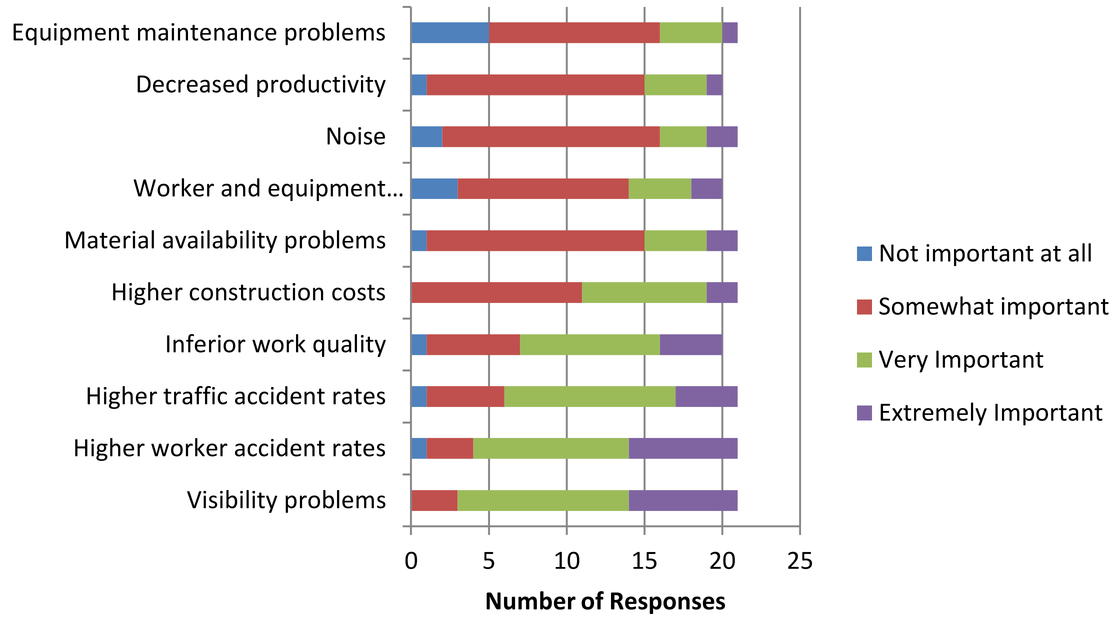


Figure 3.7. Respondent opinions on the disadvantages of performing nighttime work

As far as lane-closure policies are concerned, there was about an equal number of respondents that have and do not have policies (48 percent with policies and 52 percent without policies). The policies are usually kept by a person assigned by the construction division, and some of the policies are available online. One agency mentioned that policies vary by district and another respondent indicated they were written on a job-by-job basis.

3.3.2 Phase I Survey 2 – Quality Impacts of Nighttime Construction

There were 15 respondents from different agencies across the US regarding the quality aspect or concerns when conducting nighttime construction. Of the 15 respondents, nine of the agencies responded that nighttime work significantly impacts construction quality. In addition, all respondents reported that formal inspections of the nighttime work zone were performed routinely.

The survey instrument listed 29 different activities and respondents were asked to choose the activities with the most significant quality impacts during nighttime work. Bituminous surfaces and pavements were reported as having reduced quality when performed at night, while 11 of the respondents identified concrete sawing as having the same quality regardless of whether it is done at night or during daylight hours.

The survey also sought information about factors that affect the quality of work performed during nighttime hours (Figure 3.8).

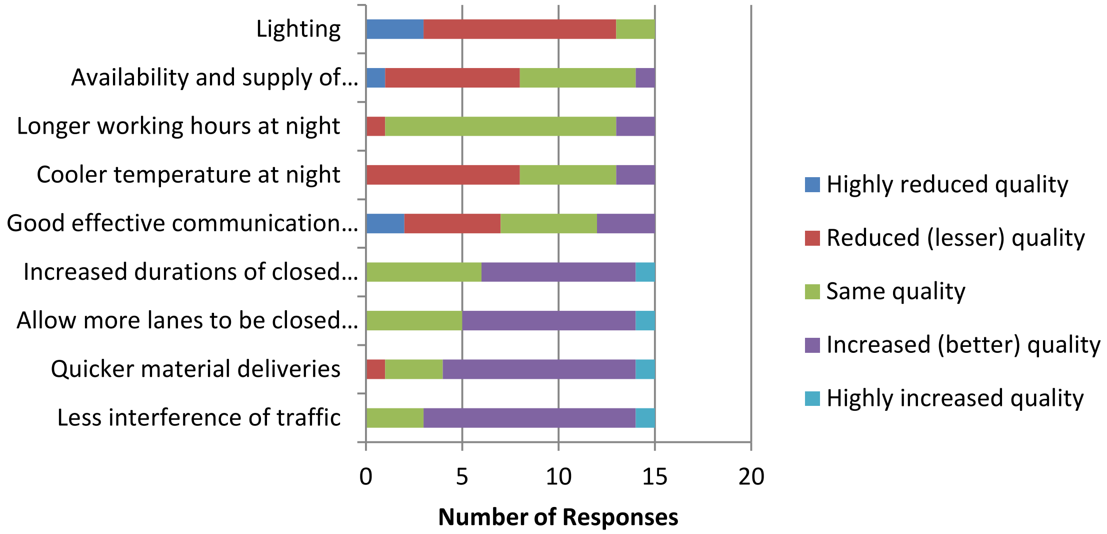


Figure 3.8. Factors that affect the quality of work performed during nighttime hours

For nighttime operations, lighting is a very important factor that needs to be seriously considered, given that it impacts quality. Conversely, less interference of traffic and quicker material deliveries results in better quality during night work. Twelve respondents identified longer working hours as a factor that has an effect on quality, regardless of whether the work is performed during the nighttime or daytime. The highest-rated factor that contributes to reduced quality is lighting.

3.3.3 Phase I Survey 2 – Safety Impacts of Nighttime Construction

The survey about nighttime construction activity impacts on safety was answered by 14 agencies from across the US. Ten of the agencies reported that construction-related accidents are not more likely to occur in nighttime work zones.

Respondents felt that rear-impacts and angle/side-impact traffic accidents were more likely to occur in nighttime work zones (Figure 3.9). Seventy-nine percent or 11 of the respondents reported that head-on collisions are not more likely to occur in nighttime work zones.

There were three contributing factors listed in the survey regarding the rate of traffic accidents at night: reduced visibility, drowsiness, and alcohol use. Alcohol use was the highest-rated factor (12 or 86 percent). Driver drowsiness was reported to have only a minor contribution. Two respondents also listed confusion, wrong-way driving, unsafe speed, and driver inattention as factors that contribute to higher accident rates at night.

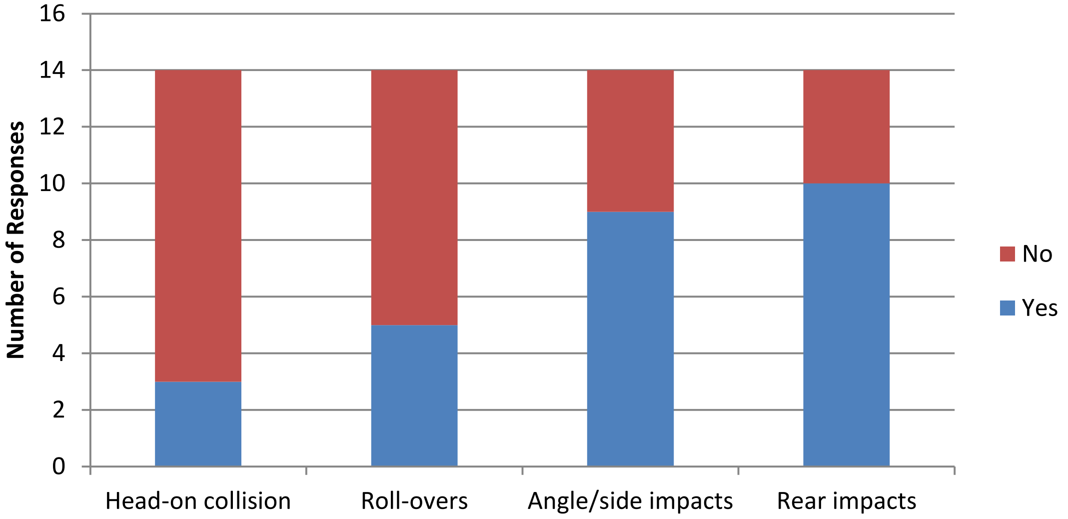
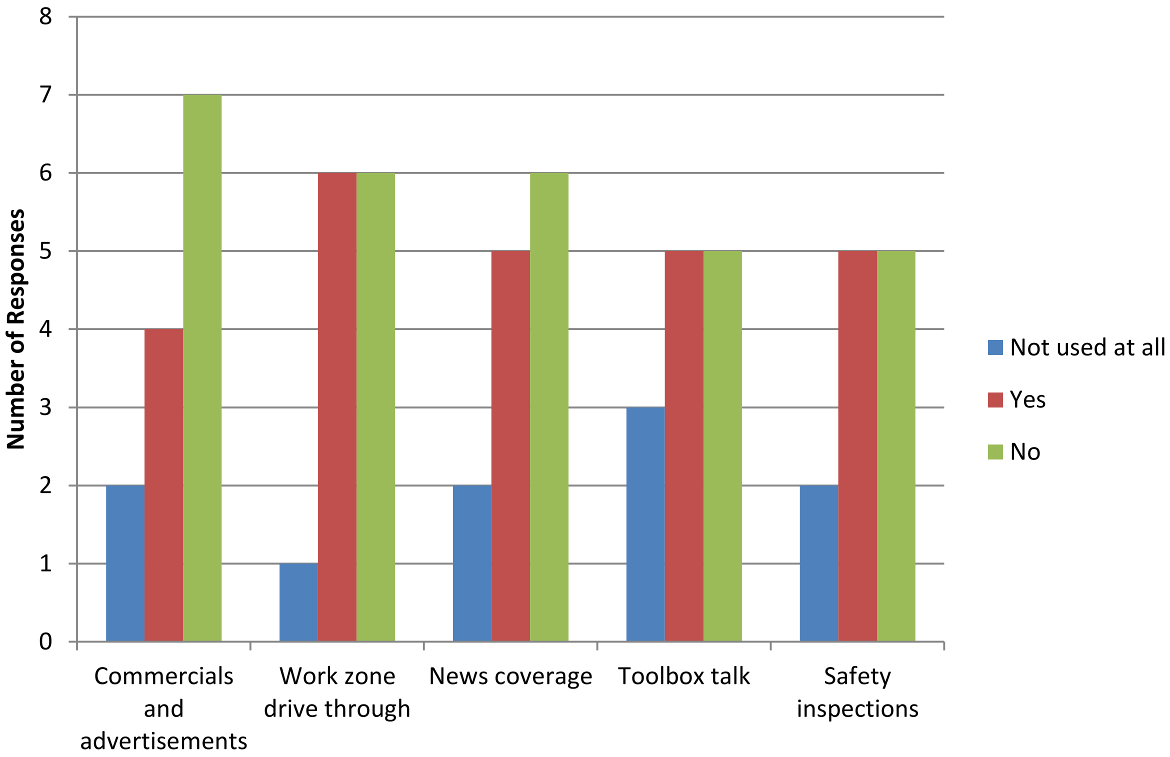


Figure 3.9. Respondent opinions on traffic accidents occurring in nighttime work zones

Six of the respondents reported that their respective agencies do have statistics on nighttime work-related accidents. (WSDOT has this information available online at www.wsdot.wa.gov/mapsdata/tdo/accidentannual.htm.)

There are various methods to address work-zone safety issues, such as toolbox talk, news coverage, commercials and advertisement, safety inspections, and work-zone drive-through inspections (Figure3.10). No agency reported that it used commercials and advertisement in a different manner to address the work-zone safety issues of nighttime construction. Work-zone drive-throughs were in use by 46 percent or 6 of the respondents to address safety issues in nighttime construction differently than daytime construction.



	Commercials and advertisements	Work zone drive through	News coverage	Toolbox talk	Safety inspections
Not used at all	2	1	2	3	2
Yes	4	6	5	5	5
No	7	6	6	5	5

Figure 3.10. Differences in addressing work-zone safety issues – nighttime and daytime work

On nighttime projects, a number of agencies indicated that personal protective equipment (PPE) is used differently compared to normal practices for daytime activities (Figure 3.11). It was not clear if these were mandated practices or just practices that were in common use. The use of on-site law enforcement, traffic-control plans, pre-job planning, lighting, safety meetings, and employee safety training also differ for nighttime activities. Whereas, the use of safety incentive programs do not vary based on nighttime or daytime construction.

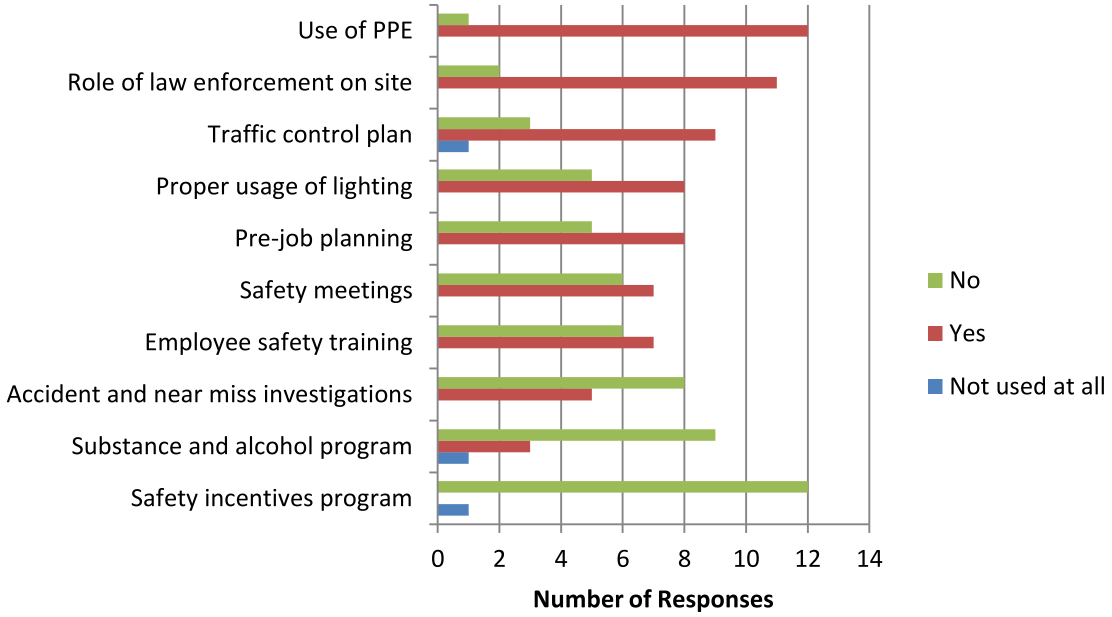


Figure 3.11. Differences in addressing work-zone safety issues – nighttime and daytime work

Based on the survey data, the important ways to improve nighttime construction work-zone safety are proper spacing of the cones and drums on the tapers and proper training for crews handling traffic control setup and breakdowns activities (Figure 3.12). Agencies also believe increasing on-site law enforcement is very important to improve the safety in nighttime work zones.

Six of the respondents indicated that they have and use safety guidelines for nighttime operations. These guidelines include agency safety manuals, the NCHRP 476 report, and the Highway Design Manual.

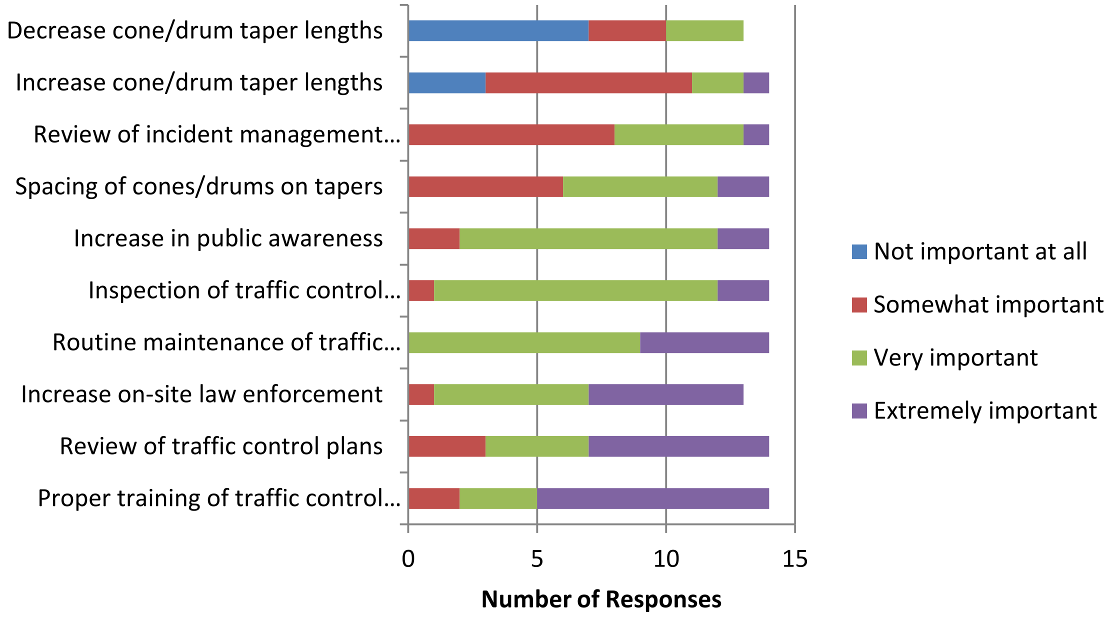


Figure 3.12. Agency opinions on ways to improve nighttime work-zone safety

3.3.4 Phase I Survey 2 – Construction Nuisances

Only 16 agencies provided responses to the nuisance survey. Therefore, the discussion presented here is from a very limited data source.

The survey did confirm that noise and light are the two primary nighttime construction nuisances with noise ranked first. Nevertheless, in response to a question about complaints received, 15 of the 16 responding agencies acknowledged complaints about noise, and 12 had complaints about lights and vibration. When further questioned about noise, light, and vibration nuisances, noise had a higher complaint ranking, followed by light, and then vibration. Evaluating the responses to the three questions, it can be concluded that there are more complaints about noise, but the most severe criticism comes from light and then vibration effects.

Nine agencies stated that they use criteria from local noise ordinances to specify the level of noise allowed in the work zone. Two responding agencies affirmed that they used specific noise control strategies and methods to minimize noise during nighttime operations. Four agencies said they used source control to minimize noise during nighttime activities. To a follow-up question, five agencies acknowledged their use of noise barriers and curtains. Only two responding agencies have a Noise Control Program for nighttime operations.

Considering light nuisances, only three agencies reported special specifications dealing with work-zone glare affecting motorists traveling through the work zone and three agencies reported special specifications for glare that affects work-zone neighbors. One agency stated that it uses innovative methods of mitigating nuisances when performing nighttime construction.

From previous studies and the literature, it is known that some agencies require contractors to adhere to certain noise (decibel) limits during nighttime construction. In many cases, these limits are the consequence of specific local ordinances. A few STAs indicated that they could receive local ordinance waivers rather easily. Other STAs stated that they had jurisdiction over the local municipalities in these matters, but that they try to abide by the local ordinances. Based on the responses to the Task 2 surveys, this issue was further investigated for the Guidebook.

3.3.5 Phase I Survey 2 – Communications Strategies

As with the nuisance survey, there were 16 respondents from different agencies across the US regarding the communication aspects of nighttime construction. All responding agencies stated that they use local news coverage to disseminate information pertaining to nighttime construction activities (Figure 3.13). Intelligent Transportation Systems (ITS) equipment is used by 15 agencies. This is followed by websites and newspapers. Ads are not used by many agencies. A few respondents reported using each of these methods differently for nighttime versus daytime construction activities.

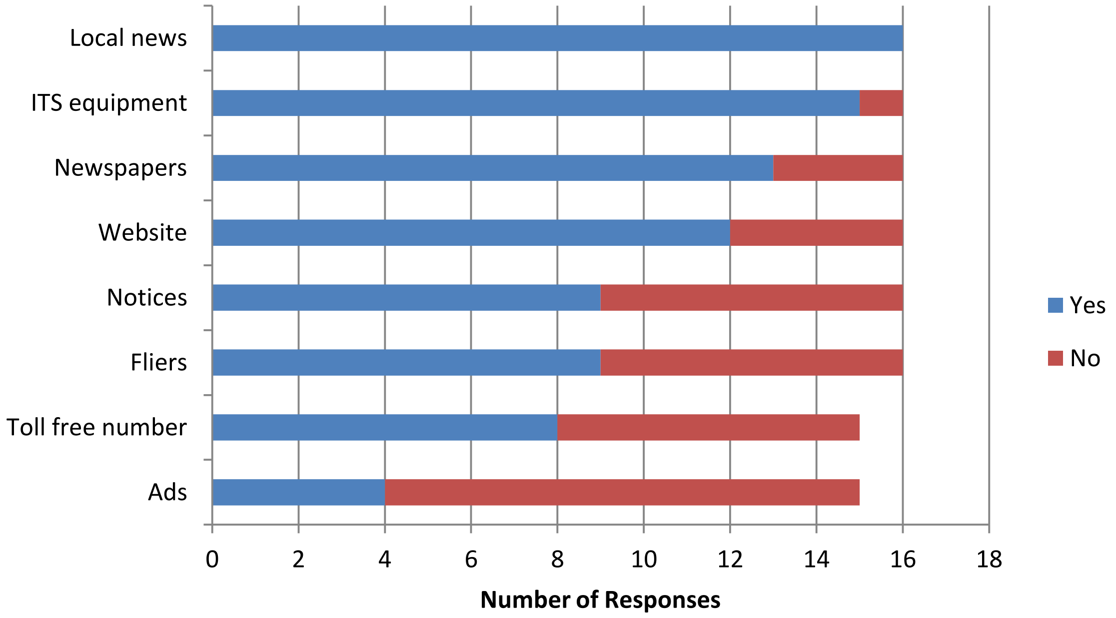


Figure 3.13. Methods of communication used by the agencies specifically for nighttime construction

Lane closures and delays are communicated by all responding agencies (Figure 3.14). Additional information reported by many agencies includes speeds, lengths, and contact information.

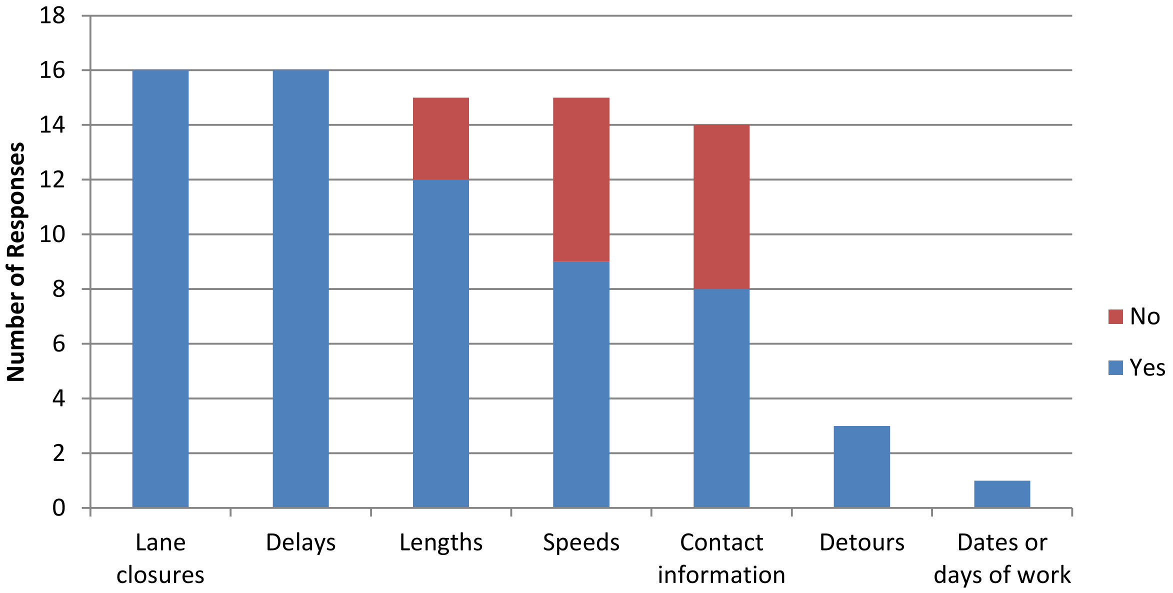


Figure 3.14. Types of information communicated

3.3.6 Phase I Survey 2 – Illumination

The survey regarding the illumination arrangements received 15 agency responses. The first question of the survey looked at the different factors affecting work-zone illumination levels (Figure 3.15). The agency respondents to this question were all of the opinion that the listed factors (work-zone geometer and size, orientation of lighting equipment, required lighting uniformity, and glare avoidance measures) impact the level of illumination on nighttime construction projects.

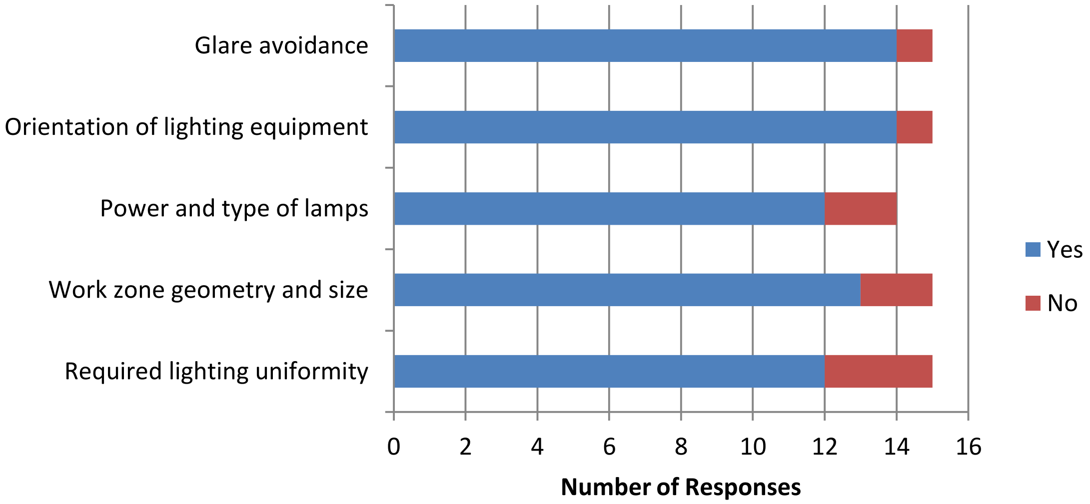


Figure 3.15. Factors influencing illumination levels

A follow-on question looked into the quality of the lighting arrangements in the individual states (Figure 3.16).

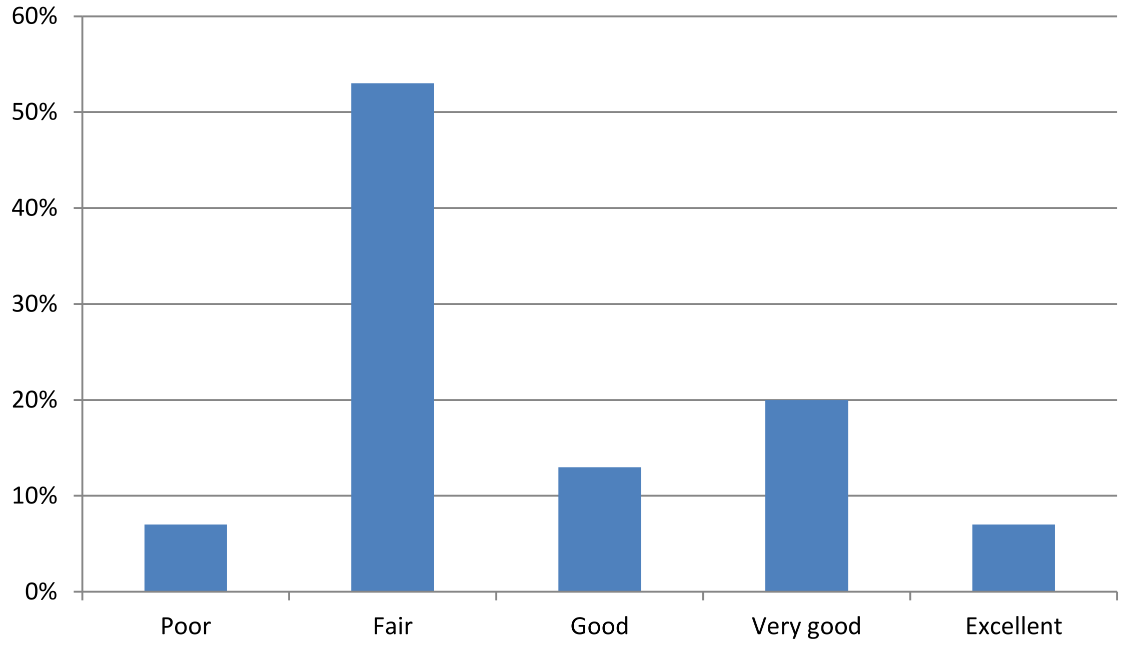


Figure 3.16. Evaluation of quality of lighting arrangements in state

The majority of the respondents believed that the level of nighttime lighting in work zones in their respective states was fair, with a few believing that the levels were good, very good, or excellent. One respondent believed that the lighting conditions in nighttime work zones in their state were poor. It is believed that the reason for this response could be partly attributed to a fact that was repeated in many work-zone illumination studies—the difficulty of evaluating lighting conditions on the job site. The fact that most respondents thought lighting conditions were fair indicates there may be some dissatisfaction that is not fully manifested due to this difficulty.

Another important question that was posed examined the impact of illumination levels required for construction tasks (Figure 3.17). The majority of respondents to this question believed that the following factors were important: condition and location of work zone, equipment used, task difficulty, and task quality requirements. The majority of respondents also believed that lighting equipment cost and availability are not important factors in determining task lighting requirements.

Figure 3.17. Factors affecting lighting requirements for construction tasks

3.3.7 Phase I Survey 2 – Productivity Impacts of Nighttime Construction

The productivity survey, which looked at the possible impact of nighttime work on construction productivity, received 13 responses. Factors that are perceived to impact nighttime construction productivity were the focus of the survey (Figure 3.18). The majority, or eight, of the respondents believed that nighttime construction has a significant impact on construction productivity. This question showed polarization between respondents about productivity effect, but the majority of the respondents believe that nighttime construction has a negative impact on productivity.

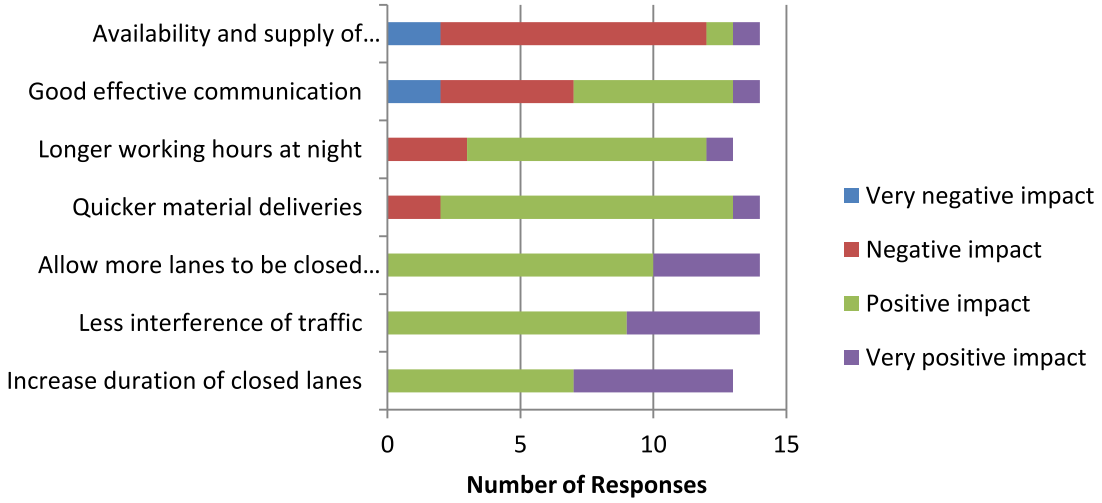


Figure 3.18. Factors affecting nighttime construction productivity

Most respondents believed that the availability of workers (or lack thereof) has a negative impact on productivity at night. A few respondents believed that communications, materials delivery, and longer worker hours at night have a negative impact on productivity. Several respondents believe that worker productivity is positively impacted by longer hours at night, which contradicts the literature about the impact of overtime and night-shift work on labor productivity. The majority of respondents believed that less interference of traffic, quicker material deliveries, more closed lanes, and the increased duration of lane closures have positive impacts on nighttime construction productivity.

One of the other interesting findings of the survey is that most agencies do not monitor contractor productivity during either daytime or nighttime work. Therefore, the question concerning differences between daytime and nighttime construction productivity monitoring methods did not yield any real information. Most agencies did not have guidelines for nighttime construction productivity.

The survey questions also focused on the impact that nighttime construction has on productivity for specific activities (Figure 3.19). The majority of respondents found that construction productivity was negatively impacted in a number of activities, such as shoulder construction work. Many respondents, however, believe that nighttime construction productivity is positively impacted in the case of concrete sawing, milling and removal, resurfacing, and bridge rehabilitation and maintenance.

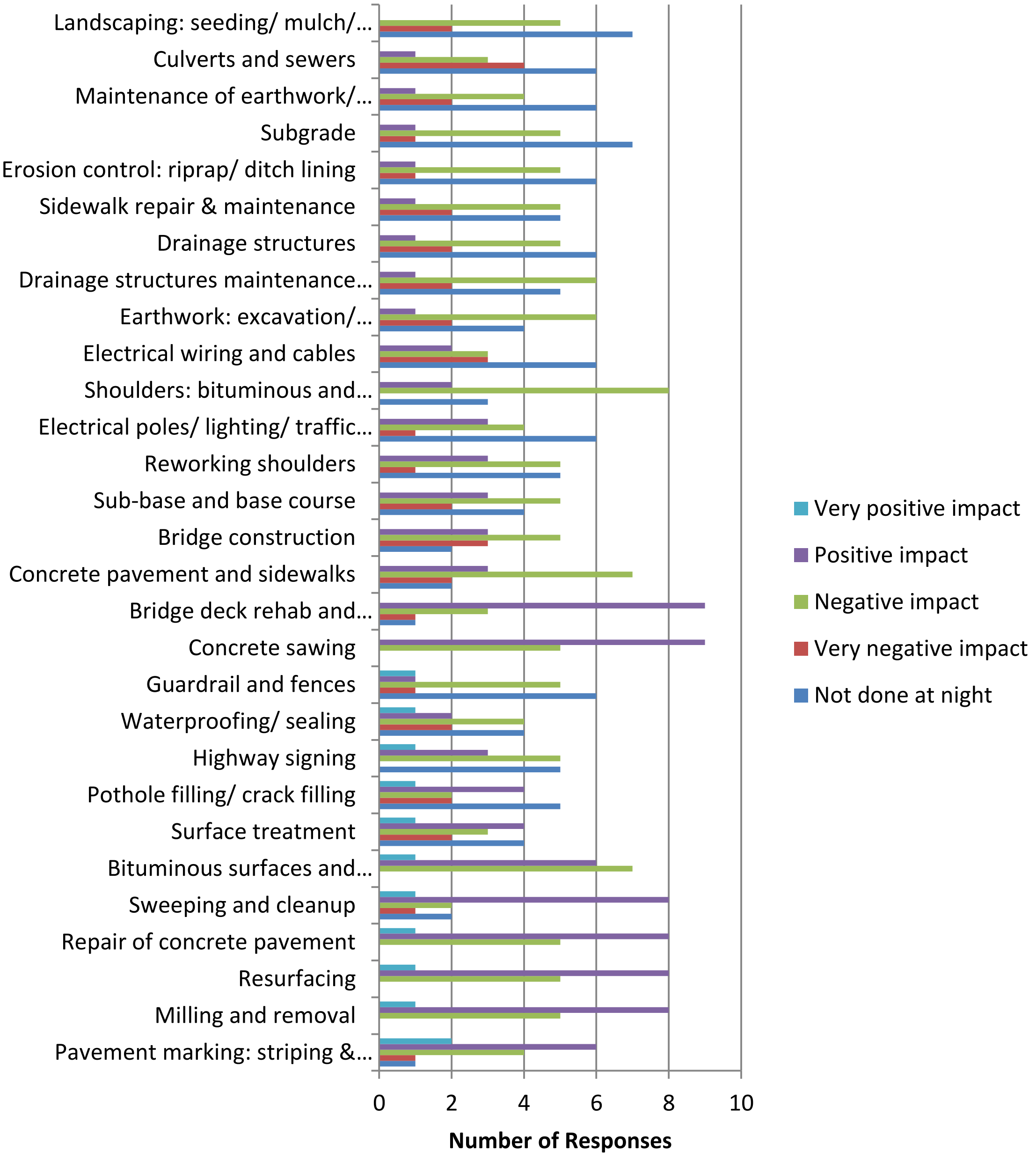


Figure 3.19. Nighttime construction impacts on activity productivity

3.3.8 Phase I Survey 2 – Work-Zone Planning Risk Analysis

The survey regarding work-zone planning risk analysis had 13 respondents from different agencies. Eleven of the agencies reported they have no formal process of nighttime construction risk analysis. Responses to the significance of the different risks are shown in Figure 3.20.

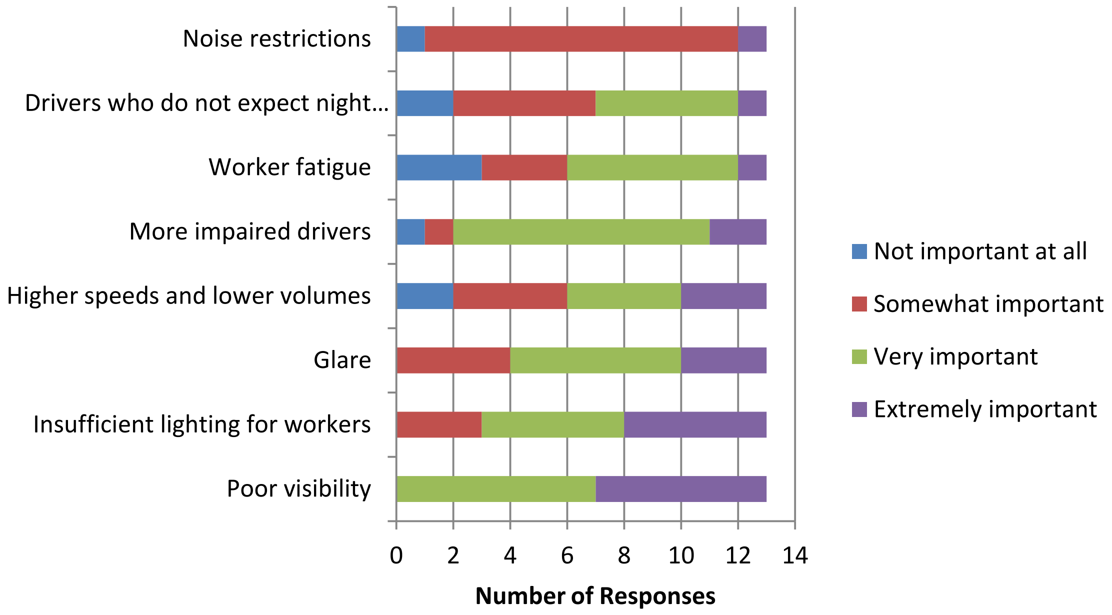


Figure 3.20. Significance of the different risks in nighttime work-zone traffic control

Eleven of the respondents rated noise reduction as somewhat significant in nighttime work-zone traffic control. Nine respondents rated impaired drivers as a very important risk; whereas, the risks of drivers who do not expect night work zones does not seem to be significant. All of the respondents agreed that poor visibility is a very or extremely important risk in nighttime work zones.

Regarding risk-identification, the survey asked about six different types of project-specific documents: project description, work breakdown structure, cost estimate, design and construction schedule, procurement plan, and listing of issues and concerns. Seven respondents or 64 percent reported on the use of the project description for risk-identification purposes. Four respondents or 36 percent use three other project-specific documents: listing of issues and concerns, cost estimate, and work breakdown structure. The least-utilized document for risk-identification purposes was the procurement plan.

Yet another question asked about other documents that an agency uses for risk-identification purposes (Figure 3.21). Historical data is the most often used programmatic document for risk identification. This is followed by checklists, final project reports, and academic studies. Only one respondent reported using a risk response plan.

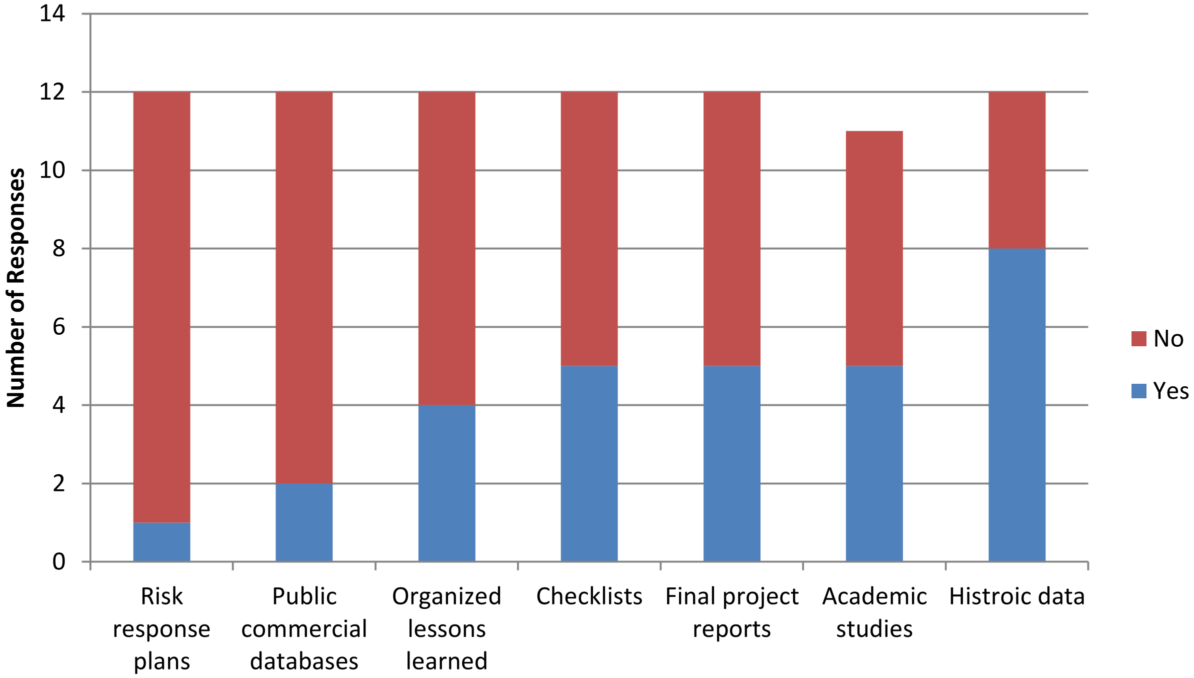


Figure 3.21. Risk-identification documents

The survey asked respondents for their opinions on the importance of a number of traffic-control risk mitigation methods (Figure 3.22). Maintaining devices was seen as extremely important by more than half of the respondents. This is also true with providing proper delineation and illuminating flagger stations. Taking care to avoid glare is seen as very or extremely important by all respondents. Using flashing beacons on leading signs was not viewed as important by half of the survey respondents.

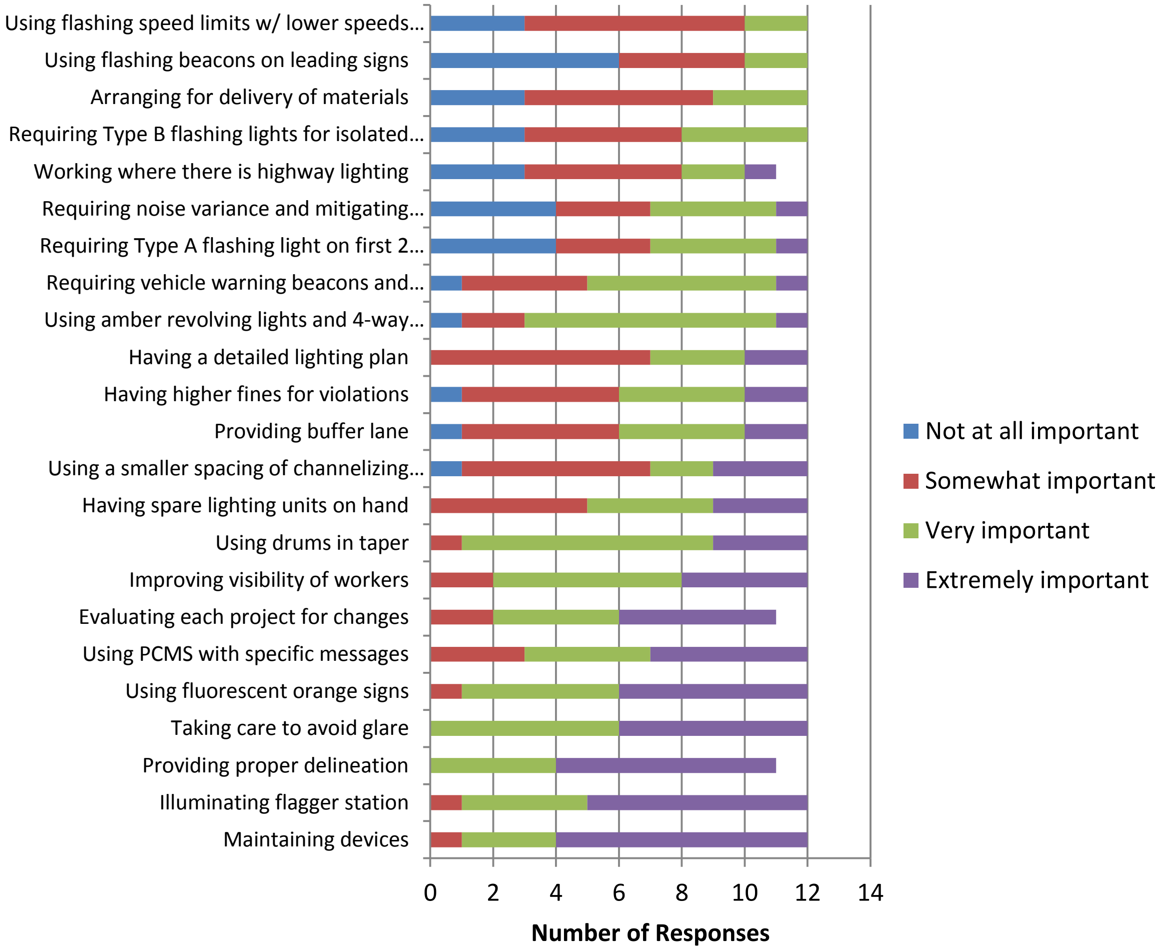


Figure 3.22. Respondent opinions on importance of traffic control risk mitigation methods

3.3.9 Phase I Survey 2 – Nighttime Construction Cost Differentials

Fifteen agencies from across the US answered the survey regarding the cost differential aspect of nighttime construction. From 15 respondents, 11 of the agencies reported not comparing the cost differences between daytime and nighttime construction.

Fourteen respondents felt that nighttime construction is either more or much more expensive than daytime construction. However, respondents felt that nighttime work is either much less expensive or less expensive to the traveling public, compared to daytime work (Figure 3.23). All but one respondent felt there was no difference in the cost of designing a nighttime project.

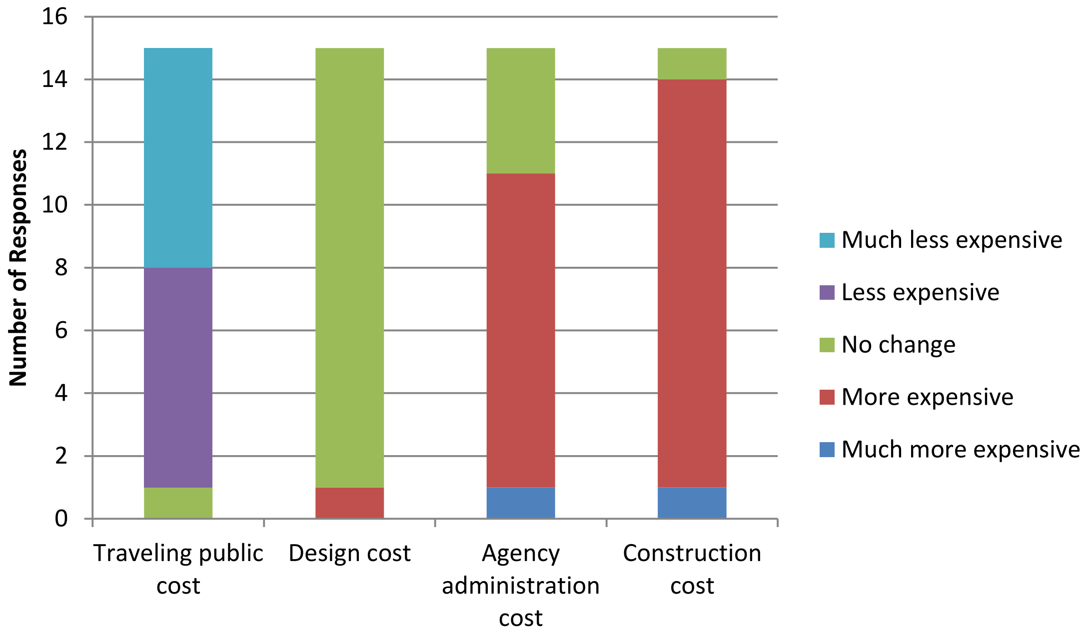


Figure 3.23. Responses on the impact of nighttime work on costs

The increase in cost of construction is further emphasized when respondents were asked to comment on specific construction activities. The survey listed eight different types of construction activities regarding changes in cost for nighttime construction (Figure 3.24). More than half of the respondents reported an increase in costs on all named activities. One of the respondents indicated that regular excavation seems to have a large increase in cost compared to when it is performed during the daytime.

The respondents were also asked for their opinions on whether reduced traffic interference and improved flexibility in design help in decreasing the cost of nighttime construction (Figure 3.25). Eighty-seven percent or 13 respondents reported that reduced traffic interference does help in decreasing the cost of nighttime construction and 67 percent or 10 respondents indicated the same for flexibility in design. One respondent listed values engineering as another aspect that helps in reducing the nighttime construction cost.

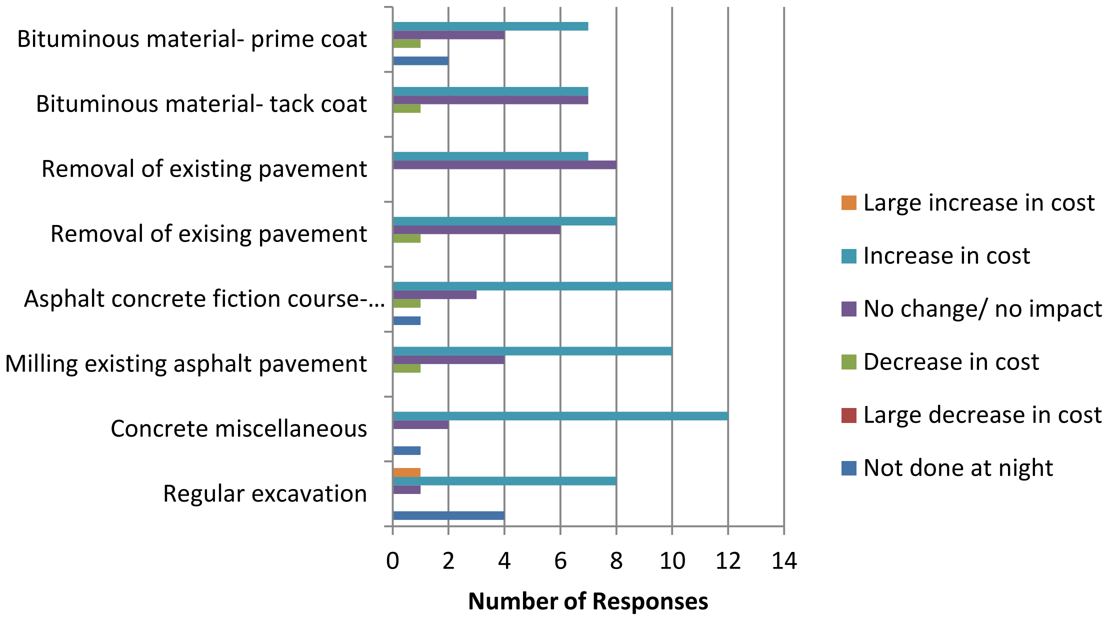


Figure 3.24. Increases in construction cost for nighttime activities

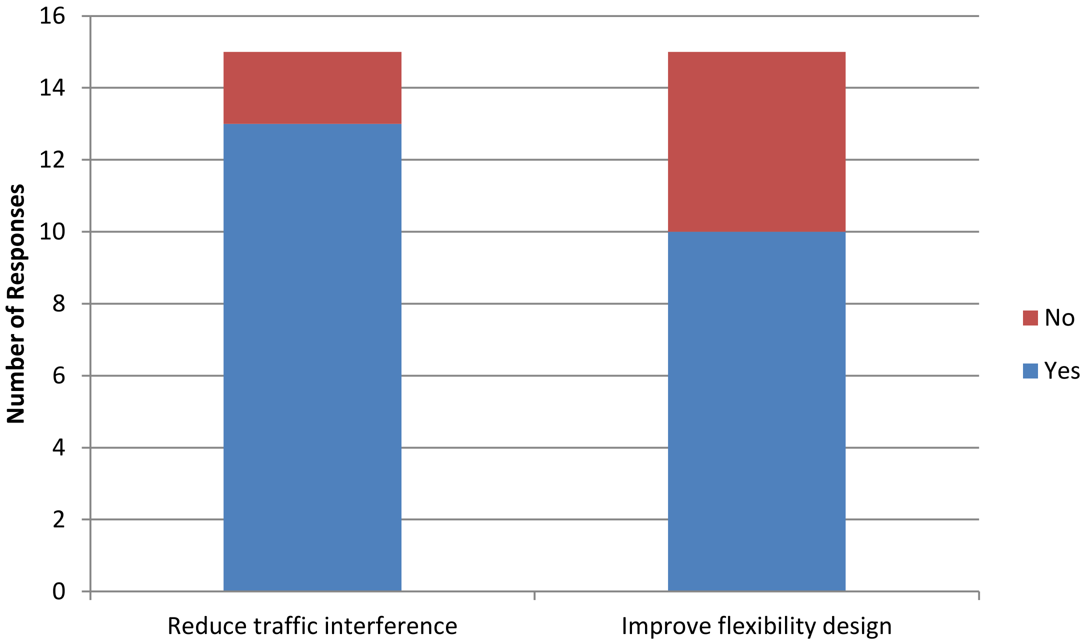


Figure 3.25. Opinions regarding ways to decrease the cost of nighttime construction

3.4 Survey 1 and 2 Conclusions

Many agencies are using nighttime construction for a variety of reasons. There are a number of aspects of project development, contracting, and construction to take into account when considering or actually conducting nighttime construction. Each of these aspects can be the responsibility of different individuals within each agency.

Considering the results of the initial survey and the general section of the second survey, a comparison of ranking of the specific aspects of this research project has been created (see Table 3.1). The rankings consider the number and type of responses.

Table 3.1. Unofficial comparison ranking

Aspect	**Quality**	**Safety**	**Nuisances**	**Communications**	**Illumination**	**Productivity**	**Risk**	**Cost**
Figure 3.4 Factors Affecting Choice	5	1	2	7	6	3		4
Figure 3.5 Problems	3	2	4		1	5		
Figure 3.7 Disadvantages	4	3	5		1	6		2

Figure 3.4 shows the factors that affect the choice of nighttime construction, based on yes and no responses. Congestion is a factor that affects the decision of all of the respondents, yet this is not one of the research areas. Safety is the first aspect of this research project that has the highest number of yes responses; therefore, it is given a rank of 1. Noise, which is a nuisance, received the next highest number of responses. The aspect that least affects the decision is communications.

Figure 3.5 depicts the areas that contribute to problems with nighttime construction. Respondents identified the listed problems as either highly contributory, moderately, lowest, or not at all. Illumination received high contributory ratings and is listed with a rank of 1. Safety has an almost even combination of highly- and moderately-contributory, and receives a rank of 2. The least contributor to the problems with nighttime construction is productivity.

Figure 3.7 illustrates the respondent opinions on the disadvantages of nighttime construction. The options are evaluated as extremely important, very important, somewhat important, and not at all important. Again, illumination receives the rank of 1 with the most important assessments. Cost is assessed in this question and receives the second rank (this includes user cost). Again, productivity receives the lowest rank of those aspects evaluated in the question.

CHAPTER 4: DATA COLLECTION

4.1 Introduction

In the second phase of the project, the research team continued to collect data regarding nighttime construction. The team used case studies/interview and field measurements (primarily) to verify the information found in Phase I. Different methods were used in different states to collect this information (see Table 4.1).

Table 4.1. Phase II data collection methods by state

	Type of Data Collection	
State	**Case Study/ Interview**	**Field Measurement**
California	x	
Connecticut	x	
Florida	x	x
Iowa	x	
Illinois	x	x
Indiana	x	x
Michigan	x	
North Carolina	x	
New Jersey	x	x
Texas	x	
Washington	x	

4.2 Case Study Methodology

Case studies involved intensive studies of specific projects or types of activity. These studies were completed using a variety of methods, including interviewing techniques, as well as direct observation (Trochim 2005). The combinations of information collection techniques were used to accumulate data on the various areas of research (productivity, cost, risk, etc.) at a program and project level. A protocol was established for the collection of information. This methodology allowed the research team to address how and why questions for the various aspects of the study (Yin 2003).

The process involved developing a set of questions for each area of interest. The survey results of Phase I formed the basis for these questions. The questions were distributed to only project or program contacts who were identified as having specific experience. The research team contacted these participants either via phone or personal visits. The questions were used for the basis of the interview and more in-depth information was obtained as the discussion progressed.

4.2.1 Selection and Respondents

Based on the responses to the survey and the literature review in Phase I, the research team identified a list of candidate state agencies to contact for further interviews or case studies. In each state, the research team investigated one or more aspects of the project (see Table 4.2).

Table 4.2. States and case study topics

State	Communications	Cost	Illumination	Nuisances	Productivity	Quality	Risk	Safety
California	x	x	x	x	x	x	x	x
Connecticut	x		x	x				
Florida	x		x	x	x	x	x	
Iowa	x	x	x	x	x	x	x	x
Illinois	x		x	x	x	x		x
Indiana	x	x	x	x	x	x	x	x
Michigan	x	x	x	x	x	x	x	x
North Carolina	x	x	x	x	x	x	x	x
New Jersey	x	x	x	x	x	x	x	x
Texas	x			x				x
Washington	x		x	x			x	x

The Phase II case study questionnaire itself contains three parts (see Appendix L). The first part requested general information. The second part requested information regarding all aspects (quality, safety, nuisances, etc.) of the research. And, the third part focused on a specific aspect.

The first and second parts of the questionnaire were included in all interviews, without prejudice for the respondent; and were a standard document. The third part was specifically geared toward an aspect of interest and was only used in specific interviews. The questions were used as a guide to insure that all important questions were discussed.

4.3 Field Measurement Methodology

In addition to collecting information through case studies, several areas of interest linked themselves well to field measurements.

4.3.1 Illumination

Many state transportation agencies have realized the importance of proper lighting arrangements in nighttime work zones. These are usually stated in the form of standard specification language, but vary in degree of detail. Some states merely require the provision of "appropriate" levels of lighting for the construction work zones, while others go into details of lighting and glare levels.

One of the main issues faced in the enforcement of these specifications is the absence of clear methods for inspecting and enforcing lighting requirements. Most STAs rely on inspections performed by their personnel by driving through the work zones. The objective of these drive-throughs is usually to ensure that glare does not present a hazard to the driving public. While this form of inspection is of great importance, it is not sufficient for ensuring that appropriate lighting is provided in the work zones. Therefore, this study aimed to collect information regarding nighttime construction lighting and the relation between the type of lighting and glare produced by such lighting, and its impact on the motorists traveling through the work zones.

This study put together a survey and questionnaire to be answered by representatives from various state STAs pertaining to the types of illumination instruments used during nighttime construction projects and their impact on construction operations (pre-specified list of activities).

The next subsection discusses the case studies from which the information was collected. It also discusses, in brief, the selection of data collection methods and their usefulness in representing the relation between lighting and its impact on nighttime construction. Further, a thorough analysis of the data collected was performed to reach reasonable conclusions and to propose recommendations on the use of type of lighting during nighttime construction (to increase productivity). A detailed discussion on productivity is included in the final subsection of this chapter.

Illumination Field Data Study Locations

Various STAs were approached for the purpose of data collection for this research study. A total of four STAs (Indiana, Illinois, Florida, and New Jersey) were contacted and approached to collect data. Different types of projects being undertaken by the STAs were observed, such mainline paving, surface milling, and bridge deck placement. A brief summary on the details of each of the case studies is provided in this subsection.

From the Indiana Department of Transportation (INDOT), two project superintendents provided details and data regarding nighttime construction in the state of Indiana. Given both were in the role of project superintendent, the information was assumed to be a general representation for INDOT in the process of collecting information.

The construction operations observed in Indiana involved the mainline paving of I-465 and milling and paving of a portion of the intersection of State Road (SR) 10 and I-66. Also included in the construction operations studied in Indiana was the bridge deck placement on I-465. Figure 4.1 shows the bridge deck placement activities on I-465. Figure 4.2 shows the stationary portable lighting equipment being used at the site.

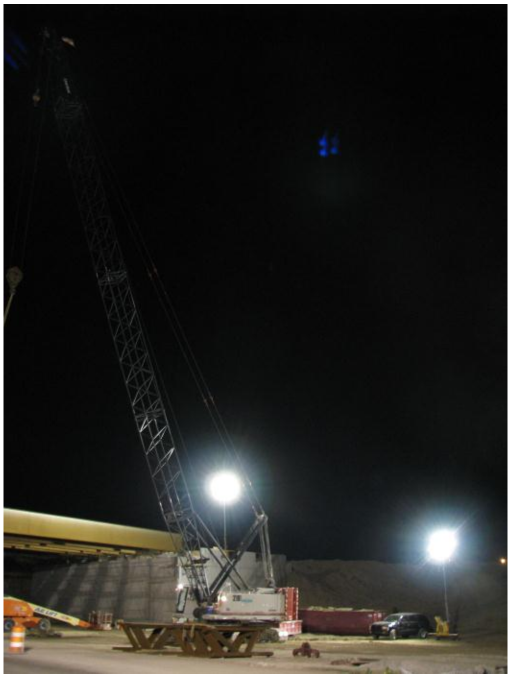


Figure 4.1. Bridge deck placement on I-465 in Indiana

Figure 4.2. Portable stationary lighting in use on I-465 bridge deck replacement in Indiana

Figure 4.3 shows the equipment-mounted balloon lighting used on SR-10 and I-66 for milling and paving of the highway.

Figure 4.3. Milling and paving on SR 10 and I-66 using equipment-mounted balloon lighting

In Illinois, a resident IDOT engineer provided critical information pertaining to this study. As a part of data collection from Illinois, construction operations, such as mainline paving of I-290, and milling, paving, and pavement marking on southbound (SB) I-55, were examined and studied. Figure 4.4 shows the mainline paving activity going on at SB I-55 where equipment-mounted balloon lighting is used similar to what is shown in Figure 4.3.

Figure 4.4. Mainline paving on SB I-55 using equipment-mounted balloon lighting

A project superintendent representing FDOT provided information pertaining to this research by giving access to study the construction operations between US 331 south/State Road (SR) 8 (I-10) to south SR 10 (US 90). The work included mainline paving, surface milling, and pavement marking. Figure 4.5 shows the equipment-mounted lighting used for milling on this project in Florida.

Figure 4.5. Surface milling in Florida using stationary and equipment-mounted lighting

Finally, a project director with the New Jersey Department of Transportation (NJDOT) provided information and access to paving and other construction operations on I-195. Figure 4.6 shows lighting equipment used while milling and paving on this project in New Jersey.

Figure 4.6. Milling and paving in New Jersey using equipment-mounted lighting

Illumination Data Collection and Analysis

Vision, visibility, and light pollution problems are regularly encountered during nighttime construction work. Nighttime construction activities require the creation of adequate lighting conditions. According to the STA representatives, the respective state agencies select the type of illumination to be used for nighttime construction based on their specification manuals.

Some of the most popular and widely used types of illumination include: (1) mobile light towers, (2) stationary balloon lighting, (3) equipment-mounted balloon lighting, (4) equipment lighting (headlights), and (5) portable lighting equipment. Almost all of the STAs interviewed saw use of at least one of these types of illumination for their nighttime construction projects. Furthermore, the STAs performed inspections of nighttime lighting frequently to ensure the lighting standards are met at the project site according to the specifications given in the manuals.

On a further detailed discussion with the STA representatives through the survey questionnaire, additional information with respect to nighttime illumination was elicited. It was observed that most of the STAs required contractors to have lighting plans before placing the lights on the project site. On the submission of these lighting plans by the contractor, the STA reviews and approves them for project initiation.

Field changes can be made to the plan as required by the conditions at the project site. Field changes typically arise due to drive-through inspections of the project site. The widely used method of checking nighttime construction lighting conditions is simply a drive-through or what might be called a “windshield check.”

However, STAs have various criteria for evaluating the lighting conditions on work zones during nighttime construction, with the most important being illuminance, glare, and light trespass. Other factors that have an impact on the evaluation criterion are the luminance and uniformity, which are derivate measurements from illuminance, and glare.

These criteria directly impact the various types of activities. On further inspection and observation, it was learned that the type of illumination, which provide adequate lighting conditions during nighttime, include mobile light towers, stationary balloon lighting, and portable lighting equipment. Closely following these types of illumination are the secondary types of equipment that are used, including equipment lighting (headlights).

The criteria for selecting the different types of illumination are directly dependent on the type of construction activity. In parallel to the survey questionnaire, site data were collected from each visited project in terms of illuminance and pavement luminance to determine the amount of glare at each location.

Lighting conditions in nighttime work zones need to satisfy a number of important lighting design requirements, which include illuminance, light uniformity, glare, light trespass, and visibility (El-Rayes et. al. 2007). This research study examined the work-zone lighting by evaluating three main parameters: (1) illuminance, (2) lighting uniformity, and (3) glare. Many

STAs have started to ensure specifications that assure the safety and quality of nighttime construction work.

These specifications usually focus on the three aforementioned lighting quality parameters. First, most standards require a minimum level of average Illuminance to be provided on the job site. This ensures the intensity of light incident on the surfaces of the project. The other criterion that STA specifications require is the level of light uniformity that ensures lighting is distributed rather equally throughout all of the construction job site. Finally, the third quality parameter specified by STAs is maximum glare, which is quantified using the levels of luminance prevalent on the site (El-Rayes and Hyari 2005a).

These STA specifications for nighttime construction work require a minimum level of average illuminance that contractors need to provide on the construction job site. Illuminance represents the time rate of flow of light measured in lumens that falls upon a surface area. The unit of measurement of illuminance is lux which is measured in lumens/m2. Illuminance can be measured on a job site using a simple device called the illuminance meter (Hyari and El-Rayes 2006a). Using the illuminance meter, the horizontal illuminance and vertical illuminance are calculated at various points around the light source. The measurement is performed by holding the illuminance meter horizontally at the specified height and taking the measurement and, for vertical illuminance, the instrument is held in a vertical position. The horizontal illuminance is represented by E_{pk}, and the vertical illuminance by VE_{ok}. From the vertical illuminance, a multiple of the same at a specific position from the light source is calculated, as represented by T_{ok} (T_{ok} = 10 ∗VEok).

Another important parameter that needs to be calculated or measured is the luminance. Luminance is the amount of light that is reflected from a surface. It is measured in candela per square meter (metric) or foot-candelas (imperial). The device used to measure luminance is called a luminance meter. Most STA specifications do not have a requirement for luminance, but it is an important parameter to measure because it determines the amount of glare. The measurement is performed by looking in the luminance meter’s viewfinder and aiming at a target surface and then taking the measurement.

Then, the uniformity ratio is calculated from the illuminance values measured at the job site. The pavement luminance is represented by L_{ogk}. Further measurements involve the calculation of uniformity ratio given by the average illuminance E_{ave} and the minimum illuminance at the darkest spot on the job site E_{min}.

Glare is calculated as the ratio of veiling luminance (amount of light falling on the observer’s eyes) to pavement luminance (amount of light reflected off pavement surfaces). Pavement luminance can be measured using the luminance meter that would be used to measure luminance at a number of targets on the pavement in the view of the observer (possibly driver of a car passing through the work zone). Veiling luminance, on the other hand, could be measured using an illuminance meter that would be held vertically at the same height as the observer’s eyes. Glare is represented as V_o (veiling luminance ration). The following set of equations summarizes the calculation of the final value for glare at various positions at the job site.

The following are measured using the illuminance meter, and the luminance meter: E_{pk},VE_{ok} (T_{ok}), and L_o.

Uniformity ratio (U) = E_{ave}/E_{min}

$VL_{ok} = (T/\Theta^n)_{ok}$ is the veiling luminance at position o from light source k

$n = 2.3 – 0.7 * \log(\Theta)_{ok}$ for $\Theta_{ok} < 2^\circ$ $n = 2$ for $\Theta_{ok} \geq 2^\circ$

veiling luminance ration (V_o) = VL_{ok}/L_o

Acceptable glare range is from 0.3 to 0.4, with glare above 1.2 considered as highly dangerous and undesirable for nighttime construction. The aforementioned measurements were collected for various work zones in different states and under different lighting conditions for a practical way of measurement and analysis.

Illuminance meters and luminance meters are used in measuring the vertical illuminance, horizontal illuminance, and pavement luminance. These three parameters are then used in calculating the veiling luminance ratio at each location on a project site and translated into the amount of glare at the work zones. Tables 4.3a, b, c, d, e, f, and g give the measurements for horizontal and vertical illuminance and pavement luminance at various project locations for various projects.

Table 4.3.a. Illuminance and luminance data collected

US331 S SR8 - SR10 FDOT										
Location	**Distance from Light Source (ft)**	**Horizontal Illuminance (Flux)**			**Vertical Illuminance (Flux) – 6ft**			**Pavement Luminance (cd/m^2)**		
		1st	**2nd**	**3rd**	**1st**	**2nd**	**3rd**	**1st**	**2nd**	**3rd**
Back of Paver	1	123	122.5	118.9	72.4	74	74.9	0.39	0.48	0.38
	5	56.4	55	55.4	63.4	84.6	50.1			
	10	30.1	31.6	34.2	36.4	58.7	34.3			
Front of Paver	1	64.2	58.5	61.6	51.9	25.4	29.1	0.32	0.33	0.38
	5	55.9	53.7	52.9	20.4	41.3	37.3			
	10	44.7	46.4	44.7	34.3	43	42.3			
Transfer Buggy Front	1	5.3	5.6	4.7	24.1	8	6.1	0.61	0.66	0.6
	5	9.8	11.5	11.1	14.5	16.9	18.9			
	10	7.8	7.3	6.8	14.4	14.6	16			
Transfer Buggy Back	1	60.8	43.2	45.4	49.9	53	45.3	0.88	0.87	0.71
	5	10.6	7.1	8.6	8.1	8	9			
	10	6.9	2.7	3.9	3.5	4.4	5.1			

Table 4.3.b. Illuminance and luminance data collected

I-195 NJDOT										
Location	**Distance from Light Source (ft)**	**Horizontal Illuminance (Flux)**			**Vertical Illuminance (Flux) – 6ft**			**Pavement Luminance (cd/m^2)**		
		1st	**2nd**	**3rd**	**1st**	**2nd**	**3rd**	**1st**	**2nd**	**3rd**
Back of Paver	1	103	108	106	354	365	355	0.31	0.24	0.25
	5	55.4	64	63	56	54	51			
	10	15	24.6	26.8	20	21	19			
Front of Paver	1	234	223	234	150	152	148	0.34	0.33	0.3
	5	73	70.4	70.3	95	94	88			
	10	24	24.9	23.1	34	33	28			
Transfer Buggy Front	1	13	15	11	2	5	1	0.29	0.27	0.34
	5	5	8	7	8	10	11			
	10	4	2	3	17	18	21			
Transfer Buggy Back	1	366	305	322	102	119	116	0.12	0.155	0.13
	5	88	92	83	65	58	63			
	10	46	44	41	46	45	48			

Table 4.3.c. Illuminance and luminance data collected

SR 10 INDOT										
Location	**Distance from Light Source (ft)**	**Horizontal Illuminance (Flux)**			**Vertical Illuminance (Flux) – 6ft**			**Pavement Luminance (cd/m^2)**		
		1st	**2nd**	**3rd**	**1st**	**2nd**	**3rd**	**1st**	**2nd**	**3rd**
End of Paver	1	470	512	612	715	721	747	0.16	0.08	0.1
	5	271	347	386	418	449	448			
	10	163	172	238	253	273	261			
Middle of Paver	1	106	178	178	236	280	232	0.07	0.05	0.25
	5	103	180	159	182	229	180			
	10	51	96	110	163	158	125			
Front end of Paver	1	85	95	89	75.7	93	88	0.27	0.27	0.4
	5	66	78	60	125	116	68			
	10	51	63	64	89	85	47			

Table 4.3.d. Illuminance and luminance data collected

I-465 INDOT												
Location			**Distance from Light Source (ft)**	**Horizontal Illuminance (Flux)**			**Vertical Illuminance (Flux) – 6ft**			**Pavement Luminance (cd/m^2)**		
X (ft)	**Y (ft)**	**Z (ft)**		**1st**	**2nd**	**3rd**	**1st**	**2nd**	**3rd**	**1st**	**2nd**	**3rd**
6	8	0	10	956	998	1003	1006	988	924	1.76	1.48	0.56
6	16	0	17.08	788	790	791	991	985	998	0.6	0.95	0.88
6	24	0	24.74	477	472	474	725	715	700	1.88	1.89	1.42
6	32	0	32.56	287	286	282	487	483	473	1.94	1.57	2.31
6	46	0	46.39	178	178	178	325	323	322	1.73	2.19	1.78
0	14	0	14	226	224	228	331	336	334	0.4	0.36	0.33
0	22	0	22	216	220	215	407	395	395	0.51	0.62	0.59
0	30	0	30	221	221	222	348	344	347	0.77	0.81	0.72
0	38	0	38	159	156	158	275	281	277	0.9	0.83	0.82

Table 4.3.e. Illuminance and luminance data collected

SB I-55 Site 1 IDOT										
Location	**Distance from Light Source (ft)**	**Horizontal Illuminance (Flux)**			**Vertical Illuminance (Flux) – 6ft**			**Pavement Luminance (cd/m^2)**		
		1st	**2nd**	**3rd**	**1st**	**2nd**	**3rd**	**1st**	**2nd**	**3rd**
End Paver	1	74	53	50.3	76	78	72.1	0.43	0.48	0.49
	5	34.8	36	39.6	61	63	62.4			
	10	20.7	30	24.9	54	57	46.4			
Front Paver	1	97.7	118	176.7	84	145	120.9	0.15	0.05	0.11
	5	47.2	67	70.4	38	74	81.2			
	10	23.2	33	37.1	31	61	53.6			
End Shuttle Buggy(2500)	1	176.7	159	167.8	97	97	125.3	0.1	0.14	0.04
	5	51.7	106	71.2	49	55	54.9			
	10	12.6	28	19.7	20	27	17.9			
Front Shuttle Buggy(2500)	1	227	258	265	275	413	423	0.07	0.09	0.03
	5	103	114	103	164	62	111			
	10	44	46	39	66	20	27			

Table 4.3.f. Illuminance and luminance data collected

SB I-55 Site 2 IDOT										
Location	**Distance from Light Source (ft)**	**Horizontal Illuminance (Flux)**			**Vertical Illuminance (Flux) – 6ft**			**Pavement Luminance (cd/m^2)**		
		1st	**2nd**	**3rd**	**1st**	**2nd**	**3rd**	**1st**	**2nd**	**3rd**
End Paver	1	208	224	215	277	228	257	0.42	0.4	0.23
	5	115	146	129	185	186	194			
	10	82	90	88	114	143	140			
Front Paver	1	46	36	86	43	45	54	0.15	0.13	0.24
	5	28	26	33	45	47	52			
	10	29	26	28	43	43	47			
End Shuttle Buggy(1500)	1	6	5	6	16	6	7	0.23	0.12	0.1
	5	6	10	10	12	14	17			
	10	7	7	7	14	15	15			
Front Shuttle Buggy(1500)	1	5	6	8	2	2	5	0.07	0.1	0.11
	5	5	4	2	6	5	5			
	10	2	3	3	7	5	3			

Table 4.3.g. Illuminance and luminance data collected

I-290 IDOT										
Location	**Distance from Light Source (ft)**	**Horizontal Illuminance (Flux)**			**Vertical Illuminance (Flux) – 6ft**			**Pavement Luminance (cd/m^2)**		
		1st	**2nd**	**3rd**	**1st**	**2nd**	**3rd**	**1st**	**2nd**	**3rd**
End of the Paver	1	766	697	692	744	747	725	2.09	2.54	2.84
	5	301	288	279	347	354	353			
	10	138	172	164	165	200	206			
Front of the Paver	1	115	111	115	56	64	58	2.36	2.73	2.38
	5	71	67	67	68	69	69			
	10	55	49	44	62	59	59			
End of the Shuttle Buggy	1	65	67	79	75	78	74	2.09	2.66	2.12
	5	31	29	28	51	52	53			
	10	30	22	24	51	52	53			
Front of the Shuttle Buggy	1	17.2	17.3	21	46.1	47.8	44.6	2.71	2.44	2.13
	5	23.1	22.5	21.2	29.2	24.4	26.3			
	10	20	15.8	17.3	29.5	27.2	27.6			

Based on the data collected, glare values were calculated for each location at each project site. The acceptable glare values were in the range of 0.2 to 0.4, with values in the range of 0.4 to 1.4 being glare that needs to be avoided and values above of 1.4 considered to be disabling glare and extremely dangerous. Table 4.4 gives the values of glare at project locations. The values that need to be reconsidered are highlighted in yellow; whereas, the extremely high values are highlighted in red.

Disabling glare was found at three locations. This was caused by excessive lighting equipment combined with the existing street lighting at those locations. On the I-465 project, where a bridge deck was being installed, there was portable lighting equipment along with stationary balloon lighting combined with the street lighting, which accounted for the high values of glare. A similar situation occurred on the SB I-55 IDOT project where there was lighting equipment combined with the lighting from the lights on the highway.

According to the specification manuals made available by the STAs, the glare values in the red highlighted cells need to be avoided to increase safety and reduce the glare drivers experience in the work zone. A proposed set of recommendations to avoid excessive glare in work zones is provided in the next subsection.

Table 4.4. Glare at various project locations

Glare						
US331 S SR8 - SR10 FDOT	**SR 10 INDOT**	**SB I-55 Site 1 IDOT**	**SB I-55 Site 2 IDOT**	**I-465 INDOT**	**I-290 IDOT**	**I-195 NJDOT**
0.24	8.64	0.22	0.98	2.42	0.40	1.81
0.31	7.55	0.26	1.05	7.18	0.28	0.39
0.33	7.30	0.35	1.19	4.23	0.24	0.24
0.14	2.72	1.52	0.37	4.05	0.03	0.62
0.19	3.12	1.22	0.54	5.30	0.05	0.56
0.37	3.80	1.48	0.81	4.16	0.08	0.31
0.03	0.37	1.54	0.09	5.92	0.04	0.01
0.05	0.64	1.11	0.19	6.40	0.04	0.06
0.08	0.74	0.73	0.31	7.04	0.07	0.20
0.08		7.87	0.04		0.03	1.12
0.02		3.46	0.11		0.02	0.90
0.02		1.88	0.17		0.04	1.08

Illumination Recommendations

To reduce glare, there are many factors that need to be considered. According to El-Rayes (2007), type of illumination, height of lighting, and rotation angle of the lighting are some of the important parameters that impact the amount of glare at the work zone. Based on these studies, the amount of glare can be minimized by the use of surrounding lighting combined with appropriate on-site lighting equipment. Also, using balloon lighting can ensure uniformity and minimize the amount of light trespass and, hence, decrease the glare.

4.3.2 Productivity

The productivity of construction operations has many definitions that range from how effective and safe workers are on the job to exact metrics of how many units of a construction product are made in a certain span of time. The definition that is most widely acceptable is the one that focuses on units produced over a span of time.

There are various factors contributing to nighttime productivity. The two main classes in which these factors can be grouped into are human factors and work environment factors. Human factors deals with the possible impact that nighttime work has on construction workers and supervisors and work environment factors deals with issues such as nighttime traffic, availability of support services, and weather conditions. It is argued that factors under each class may have a positive or negative impact on productivity for nighttime work.

The productivity of any construction operation depends to a great extent on proper management, constant improvement, and good control. These are of particular importance in nighttime construction. Various measurement techniques and modeling tools exist to study and examine the productivity of construction operations.

Research studies have collected data from various STAs to examine the effect of nighttime construction on productivity. This research employed the following steps to converge on proposing recommendations and providing guidelines to enhance nighttime construction productivity: (1) data collection from various STAs, (2) data analysis, and (3) recommendations and guidelines for nighttime construction operations productivity.

Productivity Field Data Study Locations

Various state STAs were approached for the purpose of collecting productivity data to support the research. Four STAs contacted for data. Different types of projects were observed including mainline paving, surface milling, and bridge deck placement.

INDOT provided details and data regarding nighttime construction. The construction operations that were observed in Indiana involved the mainline paving of I-465, milling and paving of a portion of the intersection of SR 10 and I-66, and a bridge deck placement on I-465. Figure 4.7 shows the I-465 bridge construction.

Figure 4.7. Construction workers performing bridge deck tie placement in Indiana

In Illinois an IDOT resident engineer provided information about mainline paving of I-290 and milling, paving, and pavement marking on SB I-55. Figure 4.8 shows workers paving a section on I-290.

Figure 4.8. Workers on I-290 performing surface milling and paving in Illinois

FDOT provided information about construction operations between US 331 S SR 8 (I-10) to S SR 10 (US 90), which included mainline paving, surface milling, and pavement marking. Finally, NJDOT provided information and access to paving and other construction operations on I-195. The following subsection discusses in detail the methods of data collection employed.

Productivity Data Collection and Analysis

Finally, a project director representing the New Jersey Department of Transportation (NJDOT) provided information and access to paving and other construction operations on I-195. Figure 4.6 shows lighting equipment used while milling and paving on this project in New Jersey.

The focus of many construction improvement programs is the acquisition of accurate and consistent labor productivity data. The quality of the data collected by these exercises usually depends on the amount of effort expended in collection. There are many sources for this data, including historical site records and productivity studies conducted using multiple methodologies.

The main focus of labor productivity measurement methods is to determine the input times for each type of work. The observations of these input times could be either continuous or discrete at intermittent intervals. The main tradeoff between these two types of observation techniques is the in amount of time needed to make the observations versus the accuracy of the data collected. A number of productivity measurement techniques have been developed. These productivity measurement techniques include direct observation method, work study, audio-visual methods, and activity sampling.

For the purpose of this research, audio-visual methods and activity sampling were adopted. Five-minute productivity ratings, using the audio-visual method and activity sampling methods, were used to examine the productivity of construction workers in a five-minute time window (Oglesby et al. 1989). Various project locations and activities were captured using a video recorder. Through these recorded videos, five-minute productivity ratings of the construction workers were determined.

All of the organizations from which data were collected represented transportation agencies for their respective states. All of the STAs use the same project management system on both nighttime and routine projects and also conduct maintenance activities at night.

Productivity is an efficiency measure that is a ratio of output of a product per labor-hour input (i.e., rate of progress or quantities installed per day). There is an intuitive correlation between nighttime work/shifts and losses in productivity. Given a pre-specified list of construction activities, questionnaire respondents were asked to describe the impact of nighttime construction on the activities. Figure 4.9 shows the percentage of respondent STAs that provided information regarding the impact of nighttime construction on the productivity of specific activities.

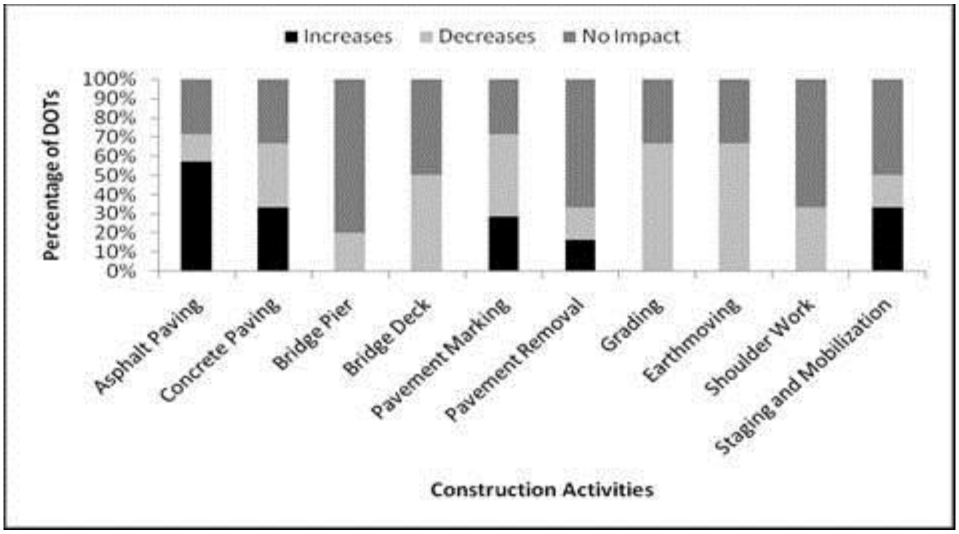


Figure 4.9. Impact of nighttime construction on activity productivity

Many of the STAs that were interviewed indicated that some activities, such as grading, earthmoving, shoulder work, bridge deck, and bridge piers, either result in a decrease in productivity or no impact by performing at night. Activities such as asphalt and concrete paving, pavement marking, and staging and mobilization had a mixed impact with STAs indicating these activities can result in either increase, decrease, or no impact to productivity, based on many other factors.

It important to understand the differences in productivity arising due to construction in daytime and nighttime early on in the project development phases. STAs that responded to this query have largely agreed that the differences should be and were considered during planning, design, and estimating phases with a consideration in award determination. However, STAs said they do not consider a difference when assigning resources for the project. Figure 4.10 summarizes the project phases in which the STAs consider the difference in activity productivity during nighttime and daytime construction.

The research team tried to determine how STAs actually measure construction productivity. They noted that INDOT and FDOT measure nighttime construction productivity by employing the documentation of construction daily diaries; whereas, IDOT does not measure nighttime construction productivity by any formal means. Information from other STAs was not available.

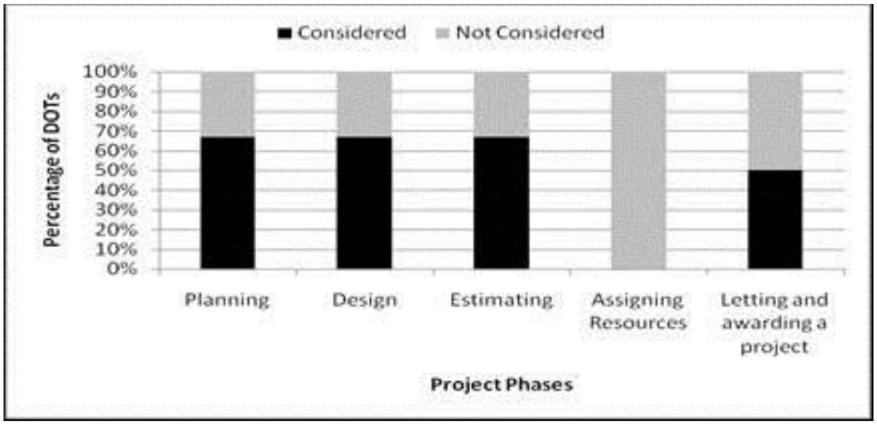


Figure 4.10. Consideration of difference in nighttime and daytime productivity by project phase

In addition to the standard information made available by the STAs for the case study, specific information was available for the case study projects. This part of the questionnaire had detailed queries to capture the impact of nighttime construction on productivity. Very few of the STAs keep records of productivity measurement. It is the contractors who keep such records.

Some agencies do conduct on-site productivity measurements with a frequency ranging from hourly measurement to weekly measurement of worker productivity. Some of the measures that the STAs employ in measuring construction productivity include contractor reports, agency personnel reports, photography, time-lapse videography, activity sampling, and random on-site inspection.

STAs had different opinions on the percentage of increase or decrease in productivity of construction activities for nighttime work. INDOT indicated there is always a decrease in productivity on nighttime construction. The impact ranges from 12 to 45 percent, with concrete patching resulting in a 12 percent decrease and grading and earthmoving activities resulting in as much as a 45 percent decrease. Most of the other agencies conceded they were not subject experts in determining figures for nighttime productivity.

It is important to know the factors affecting productivity during nighttime construction. Representatives from STAs who responded to the survey and questionnaire were asked to rank a given list of factors that would impact nighttime construction productivity. The main factors identified as the most important were availability of labor, visibility and lighting, and traffic flow. Other factors, according to lesser impact, include weather conditions, materials delivery, worker fatigue, and inspections and approvals.

Five-minute productivity ratings were performed to capture worker productivity during the nighttime construction. The five-minute rating technique is an effective method for a general work evaluation (Oglesby et al. 1989). The main purposes for adopting this technique were to (1) create awareness on the part of management of delay in a job and indicate its order of magnitude and (2) measure the effectiveness of the construction crew.

The five-minute rating is a method for measuring productivity that looks at workers actively working versus people not working in a five-minute time span. With this method, *effectiveness* is the ratio of workers performing work over the total number of workers in the crew.

To create a five-minute rating, the observers record observations of a crew without being conspicuous about it. In this way, crew members are not aware of being observed and do not react to the observer's presence.

The five-minute rating technique is so named because of the rule that no crew should be observed for less than five minutes. A rule of thumb is that the minimum observation time, expressed in minutes, should be equal to the number of workers in the crew. Table 4.5 shows a five-minute ratings for a crew working on a bridge deck placement as a part of nighttime construction activity under INDOT.

Table 4.5. Five-minute rating for bridge deck placement on I-465

Start Time	Harness Helper	Ironworkers					Description
		Beam Placing	Left Bolts Tightening		Right Bolt Tightening		
	1	2	3	4	5	6	
11:46 p.m.	✓						Crew waiting for the Steel beam to be hoisted.
11:48 p.m.	✓						Crew waiting for the Steel beam to be hoisted.
11:50 p.m.		✓					Landing Steel beam for placing.
11:52 p.m.		✓					Landing Steel beam for placing.
11:54 p.m.			✓	✓	✓	✓	Installing bolts for the beam joints.
11:56 p.m.			✓	✓	✓	✓	Installing bolts for the beam joints.
11:58 p.m.			✓	✓	✓	✓	Installing bolts for the beam joints.
12:00 p.m.			✓	✓	✓	✓	Installing bolts for the beam joints.
12:02 p.m.			✓	✓	✓	✓	Installing bolts for the beam joints.
12:04 p.m.		✓					Unhook the crane.
	2	**3**	**5**	**5**	**5**	**5**	**Effective unit totals**

Total Man Units	**60**
Effective Unit Totals	**25**
Effectiveness	**41.67 percent**

Similar ratings were obtained from each of the projects visited and the effectiveness of each construction crew was calculated. Figure 4.11 shows the crew effectiveness at various project locations and for various construction operations.

It was observed that the effectiveness of the construction crew on all of the projects was 50 percent and below. This low percentage of effectiveness is tied to factors as discussed and observed from the survey data that were collected. Two of the primary factors affecting worker productivity were visibility and lighting.

The results show the need for proposing recommendations to improve nighttime construction operation productivity.

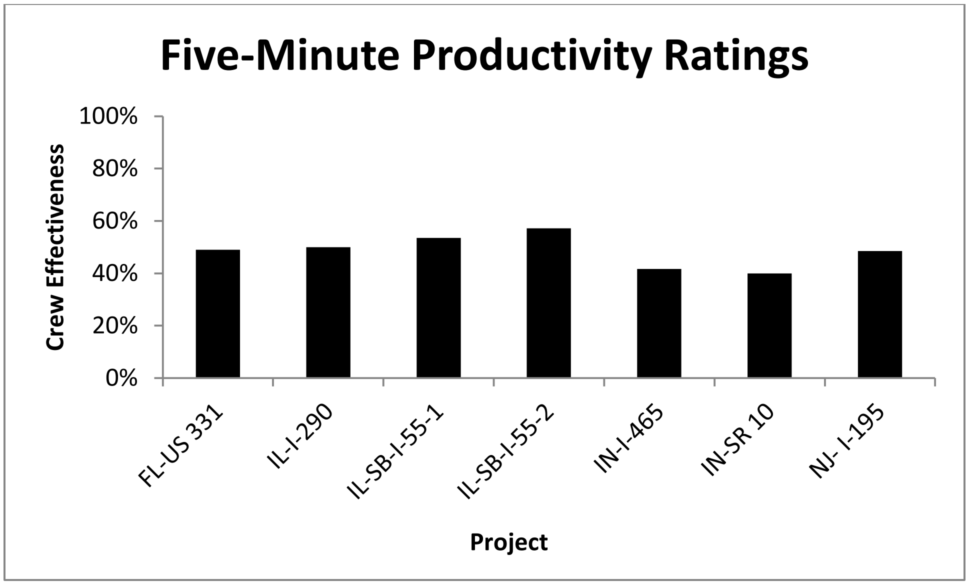


Figure 4.11. Five-minute ratings from various projects

Productivity Recommendations

Various factors impact nighttime construction operation productivity. The two important classes of these factors involve human factors and work environment factors. Recommendations for both these classes of factors can result in increased productivity during nighttime construction.

1. *Human Factors*

Worker fatigue, length of working shifts, and number of shifts are important human factors, which impact productivity of construction operations at night directly. By providing enough time for a particular crew member to recuperate before starting another shift decreases the fatigue in crew members. Furthermore, decreasing the nighttime shift length to a reasonable time range, eight to nine hours, could also motivate workers and improve their productivity.

2. *Work Environment Factors*

Visibility and lighting are critical work environment factors affecting nighttime construction productivity. Abiding by STA specifications for lighting results in increased nighttime construction productivity. The type of illumination and the relation between illumination and productivity is discussed in the Guide chapter on Illumination.

CHAPTER 5: GUIDEBOOK DEVELOPMENT

The Guidebook developed through this research was based on information gathered from both phases of this project, with the objective being to provide a practical guide for transportation agencies to use in planning and conducting nighttime construction actives. The text of the guide was kept to a minimum in an effort to provide a reference to users that would be quick and easy to use, yet provide the critical information.

The Guidebook provides a practice-oriented presentation of nighttime construction issues. This information is provided in chapters specific for each of the nighttime construction challenges. Most of the information and chapters are specific for nighttime activities, while others are more general, primarily because practices are not different between daytime and nighttime construction.

5.1 Guidebook Content

Following is an outline of the structure and description of each chapter for the final draft of the Guidebook.

Chapter 1: Introduction and Framework

The first chapter provides readers with an understanding of the challenges faced in nighttime construction. It also provides them with an understanding of the Guidebook development process and its layout, including a short discussion of the development of the information in the Guidebook.

Chapter 2: Risk

Risks inherent to construction work zones are numerous. The obvious risks are related to safety and include vehicle intrusions in work zones, workers being struck by intruding vehicles, workers struck by construction equipment, and construction equipment intrusion in operational lanes. But, there are other risks in nighttime construction related to quality, costs, communications, and nuisances. This chapter introduces these risks and includes a discussion on risk management. The remainder of the Guidebook chapters can then be used to address these risks.

Chapter 3: Illumination

Good illumination is an imperative to successfully completing a nighttime project. Therefore, this is a unique and critical aspect to nighttime activities impacting safety, productivity, quality, and cost. This chapter presents lighting requirements for highway construction, as well as potential lighting guidelines for differing nighttime construction activities.

Chapter 4: Nuisances

Several types of control mechanisms exist for noise nuisances during highway construction and these include source, path, and receptor controls. This chapter explores each type of control mechanism and discusses methods for controlling nighttime construction nuisances. The chapter briefly touches on vibration and dust nuisances. An important aspect of nuisance migration is communications, which is discussed in this chapter and also in a separate communications chapter.

Chapter 5: Productivity

The productivity level of nighttime construction is one area that has not been researched in depth, with most of the literature simply stating perceptions. This chapter presents an overview of issues and ways to improve productivity, as well as potential pitfalls that may be encountered.

Chapter 6: Quality

Every STA seeks to provide quality projects. Quality is often one of the keys in contractor payment. This is linked to the inspectability of the product being delivered. This chapter provides information for the visual requirements in the inspection for different types of work, along with information from various agencies on quality efforts in nighttime construction.

Chapter 7: Cost

Cost and the factors that impact nighttime construction costs are discussed in this chapter. Information is provided about how the factors affect costs, together with guidance on what to consider when planning and budgeting nighttime construction activities.

Chapter 8: Safety

Safety on nighttime work impacts both the traveling public and those performing the work. This chapter examines the safety issues in both areas.

Chapter 9: Communications

Many complaints about nighttime construction nuisances can be mitigated by a good communications program. This chapter explores both communications issues and the necessary communications within the STA, with contractors, and with the public at large (including politicians and the media).

Chapter 10: Interactions

None of the challenges can be addressed in isolation of the others. Therefore, this chapter calls further attention to these interactions.

Chapter 11: Summary for Implementation and Keys to Success

The conclusions of the Guidebook offer an overview perspective of the information and a path forward for nighttime project success.

References

Source information for the citations in the Guidebook is provided in the References.

Acronyms and Abbreviations

A look-up table for acronyms and abbreviations is provided.

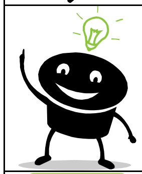
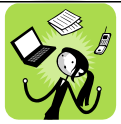
Appendix: Sample Safety Quiz

The appendix contains a sample toolbox talk written quiz and answer sheet on safety activity responsibilities.

5.2 Chapter Content/Structure

Each chapter of the Guidebook has three sections: introduction, body, and conclusion. In each of these sections, certain types of information are highlighted to call attention to important details and for quick reference. These include key take-aways, tips, and directions to other resources (see Table 5.1.)

Table 5.1 Guidebook content

Symbol	**Section Name**	**Content**
	Key Take-Aways/ Information	• An indicator of key, not-to-forget information--for quick reference
	Tips	• Possible tips for use of information
	Other Resources	• Sources of useful information ○ Internet ○ Literature ○ Agency or group ○ Reports

CHAPTER 6: CONCLUSIONS

Nighttime construction and maintenance activities are becoming more common. This has prompted a number of research projects to look at the impacts of nighttime activities compared to activities completed during the day. The objective of this research was to investigate the impact of nighttime work on risk, illumination, nuisances, productivity, quality, cost, safety, and communications. The primary deliverable was the Nighttime Construction Project Guidebook for transportation agencies.

However, this Phase II Final Report is chock full of information on the research itself (and findings) not contained in the Guidebook.

6.1 Summary of Findings

There are a number of perceived advantages and disadvantages to conducting construction and maintenance activities at night (Elrahman 2008). Through the process of this project, it became evident that many perceived disadvantages can be mitigated to limit their impact and that, in most cases, with good planning, nighttime construction can be accomplished safely at no cost disadvantage. The advantage in terms of less congestion for the traveling public cannot be measured. As with any project, appropriate planning is the key to success.

Each of the areas of interest was explored individually. However, there is a great deal of interaction between the areas and each one of them is not mutually exclusive. For example, nighttime projects require lighting. This requirement will cost additional funds, which could be considered an issue. However, good lighting improves productivity, quality, and safety of the nighttime job site.

The final findings were developed into a set of keys for success (see Table 6.1).

6.2 Additional Research Ideas

There remains much interest in nighttime construction and much concern about several specific issues. This research effort found there are several areas that are different from daytime construction, yet, there are other areas that are very similar. Future research should take a more structured assessment of productivity and costs.

Table 6.1 Keys to success on nighttime projects

Area	Key to Success
Illumination	Provide proper illumination through planning, project design, and by specification. Required for productivity, quality, and safety.
Nuisances	Write nuisance control measures into the project specifications.
Productivity	Detailed planning and scheduling, with extra labor training, improve productivity.
Quality	Specify the desired quality and note that some activities/products benefit from cooler temperatures and less traffic congestion.
Cost	Reduce lighting costs by designing and phasing the project so that permanent lighting is installed early. Consider the additional costs of lighting, nuisance mitigation, and traffic control in the estimate, but also consider productivity impacts of less congestion and longer work periods.
Safety	Safety is the priority on every job—for both the workers and the public. Night work requires detailed traffic-control planning.
Communications	Provide honest, timely information regarding the project to the public. On another note, communications-wise, on-site personnel must have authority to make decisions.

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ACRONYMS AND ABBREVIATIONS

AACEI	Association for the Advancement of Cost Engineering International
AASHTO	American Association of State Highway and Transportation Officials
ADT	average daily traffic
ATREL	Advanced Transportation Research and Engineering Laboratory
ASCE	American Society of Civil Engineers
Caltrans	California Department of Transportation
CII	Construction Industry Institute
CPMS	Construction Productivity Metrics System
FARS	Fatality Analysis Reporting System
FDOT	Florida Department of Transportation
EEG	electroencephalogram
GC	general contractor
GPS	global positioning system
HMI	hydrargyrum medium-arc iodide
ICT	Illinois Center for Transportation
IDOT	Illinois Department of Transportation
IESNA	Illuminating Engineering Society of North America
IFQM	Internet Facilitated Quality Management
INDOT	Indiana Department of Transportation
ITS	Intelligent Transportation Systems
JPEG	Joint Photographic Experts Group (which created the file compression format)
LUMINA	a system developed to measure the luminance of safety vests in nighttime conditions
MUTCD	Manual on Uniform Traffic Control
ATREL	Advanced Transportation Research and Engineering Laboratory
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NJDOT	New Jersey Department of Transportation
NYSDOT	New York State Department of Transportation
ODOT	Oregon Department of Transportation
PAF	prevention–appraisal–failure
PPE	personal protective equipment
QMS	Quality Management Systems
SB	southbound
SR	State Road

SRMP	short run marginal productivity
STA	state transportation agency
TC	Traffic control
TRB	Transportation Research Board
TRIS	Transportation Research Information Services
WSDOT	Washington State DOT

APPENDIX A: PHASE I SURVEY 1

Nighttime Construction - Initial Survey

Created: August 17 2009, 6:45 PM
Last Modified: August 17 2009, 6:45 PM
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National Cooperative Highway Research Program (NCHRP)

Project 10-78
Nighttime Construction Impacts on Safety, Quality, and Productivity

Page 1 - Heading

Part A: Demographic Information

Page 1 - Question 1 - Open Ended - One or More Lines with Prompt

Please provide your information below:

Name
Current Position
Agency
Phone Number
Email
Years of experience with DOT
Years of experience dealing with nighttime construction

Page 2 - Heading

Part B: Nighttime Construction

Page 2 - Question 2 - Yes or No

Does your agency use nighttime construction?

○ Yes
○ No [Skip to 8]

Page 3 - Question 3 - Choice - Multiple Answers (Bullets)

At what project development stage(s) does your organization most typically decide to perform nighttime construction?

- ☐ Planning
- ☐ Programming
- ☐ Advance Planning / Preliminary Design
- ☐ Final Design
- ☐ Letting
- ☐ Award
- ☐ Construction
- ☐ Not Sure / Don’t know

Page 3 - Question 4 - Choice - Multiple Answers (Bullets)

Who, within your agency makes decisions regarding when to engage in nighttime work?

- ☐ Central Office
- ☐ District Office
- ☐ Construction Office
- ☐ Project Manager
- ☐ Not sure / Don’t know
- ☐ Others, please specify

Page 4 - Question 5 - Rating Scale - Matrix

What are the factors that affect your choice to use nighttime construction?

	Yes	No
Congestion	○	○
Safety	○	○
Traffic Control	○	○
Public Relations	○	○
User Cost	○	○
Scheduling	○	○
Lighting	○	○
Noise	○	○
Worker Condition	○	○
Productivity	○	○
Driver Condition	○	○
Accident cost	○	○
Quality	○	○
Construction Cost	○	○
Maintenance Cost	○	○
Air Quality	○	○
Fuel Consumption	○	○
Communication Supervision	○	○
Availability of Material/Equipment Repair	○	○

Page 4 - Question 6 - Open Ended - One Line

Please specify any additional factors that affect your choice to use nighttime construction that are not listed in the previous question.

Page 5 - Question 7 - Yes or No

Does your agency have guidelines/ specification for performing nighttime construction?

- ○ Yes
- ○ No [Skip to 7]
- ○ If yes, please provide web link

Page 6 - Question 8 - Yes or No

Does it differ from the daytime project specification?

- ○ Yes
- ○ No

Page 7 - Heading

Based on your experience and knowledge, please suggest the most appropriate person in your agency that is suitable to provide information in the next survey for the following nighttime construction aspects:

Page 7 - Question 9 - Open Ended - One or More Lines with Prompt

Nighttime Construction Aspect: Quality

- ✎ Contact Person
- ✎ Current Position/Title
- ✎ Telephone
- ✎ Email address

Page 7 - Question 10 - Open Ended - One or More Lines with Prompt

Nighttime Construction Aspect: Safety

- ✎ Contact Person
- ✎ Current Position/Title
- ✎ Telephone
- ✎ Email address

Page 7 - Question 11 - Open Ended - One or More Lines with Prompt

Nighttime Construction Aspect: Nuisances

- ✎ Contact Person
- ✎ Current Position/Title
- ✎ Telephone
- ✎ Email address

Page 7 - Question 12 - Open Ended - One or More Lines with Prompt

Construction Aspect: Communication within the DOT

- Contact Person
- Current Position/Title
- Telephone
- Email address

Page 7 - Question 13 - Open Ended - One or More Lines with Prompt

Nighttime Construction Aspect: Communication with the public

- Contact Person
- Current Position/Title
- Telephone
- Email address

Page 7 - Question 14 - Open Ended - One or More Lines with Prompt

Nighttime Construction Aspect: Illumination

- Contact Person
- Current Position/Title
- Telephone
- Email address

Page 7 - Question 15 - Open Ended - One or More Lines with Prompt

Nighttime Construction Aspect: Productivity

- Contact Person
- Current Position/Title
- Telephone
- Email address

Page 7 - Question 16 - Open Ended - One or More Lines with Prompt

Nighttime Construction Aspect: Risk

- Contact Person
- Current Position/Title
- Telephone
- Email address

Page 7 - Question 17 - Open Ended - One or More Lines with Prompt

Nighttime Construction Aspect: Cost

- Contact Person
- Current Position/Title
- Telephone
- Email address

Unconditional Skip to End

Page 8 - Heading

Based on your experience and knowledge, please suggest the most appropriate person in your agency that is suitable to provide information in the next survey for the following aspects:

Page 8 - Question 18 - Open Ended - One or More Lines with Prompt

Construction Aspect: Quality

- Contact Person
- Current Position/Title
- Telephone
- Email address

Page 8 - Question 19 - Open Ended - One or More Lines with Prompt

Construction Aspect: Safety

- Contact Person
- Current Position/Title
- Telephone
- Email address

Page 8 - Question 20 - Open Ended - One or More Lines with Prompt

Construction Aspect: Nuisances

- Contact Person
- Current Position/Title
- Telephone
- Email address

Page 8 - Question 21 - Open Ended - One or More Lines with Prompt

Construction Aspect: Communication within the DOT

- Contact Person
- Current Position/Title
- Telephone
- Email address

Page 8 - Question 22 - Open Ended - One or More Lines with Prompt

Construction Aspect: Communication with the public

- Contact Person
- Current Position/Title
- Telephone
- Email address

Page 8 - Question 23 - Open Ended - One or More Lines with Prompt

Construction Aspect: Illumination

- Contact Person
- Current Position/Title
- Telephone
- Email address

Page 8 - Question 24 - Open Ended - One or More Lines with Prompt

Construction Aspect: Productivity

- Contact Person
- Current Position/Title
- Telephone
- Email address

Page 8 - Question 25 - Open Ended - One or More Lines with Prompt

Construction Aspect: Risk

- Contact Person
- Current Position/Title
- Telephone
- Email address

Page 8 - Question 26 - Open Ended - One or More Lines with Prompt

Construction Aspect: Cost

- Contact Person
- Current Position/Title
- Telephone
- Email address

Thank You Page

Thank you for completing the questionnaire.

If you have any additional comments, please contact:

Jennifer S. Shane, Ph.D.
Iowa State University
498 Town Engineering
Ames, IA 50011
jsshane@iastate.edu
Phone: 515.294.1703
Fax: 515.294.3845

Screen Out Page

Thank you for your willingness to participate, however, we are looking for DOTs that perform nighttime construction.

Over Quota Page

Thank you for your willingness to participate, however, this survey is now closed.

Survey Closed Page

(Standard - Zoomerang branding)

APPENDIX B: PHASE I SURVEY 2-GENERAL

zoomerang

Nighttime Construction - 2nd Survey (Part I: General)

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National Cooperative Highway Research Program (NCHRP)

Project 10-78
Nighttime Construction Impacts on Safety, Quality, and Productivity

Page 1 - Heading

Part I: General

Page 1 - Question 1 - Open Ended - One or More Lines with Prompt

Please provide your information below:

✎ Name ....
✎ Current Position ....
✎ Agency ....
✎ Phone Number ....
✎ Email ....
✎ Years of experience with DOT ....
✎ Years of experience dealing with nighttime construction ....

Page 1 - Question 2 - Yes or No

Do you encounter any problems associated with a night schedule?

○ Yes
○ No

Page 1 - Question 3 - Rating Scale - Matrix

In your opinion, do the following general areas contribute problems to nighttime construction?

	Does not contribute at all	**Least contribute**	**Moderately contribute**	**Highly contribute**
Quality	○	○	○	○
Lighting	○	○	○	○
Safety	○	○	○	○

Productivity	○	○	○	○
Public Irritation	○	○	○	○
Equipment maintenance	○	○	○	○
Employee Morale	○	○	○	○
Traffic Control	○	○	○	○
Quality	○	○	○	○

Page 1 - Question 4 - Open Ended - One Line

Please specify any additional general areas that contribute problems to nighttime construction which are not listed in the previous question.

Page 2 - Question 5 - Rating Scale - Matrix

Which of the following maintenance tasks does your agency usually performs during nighttime operations?

	Yes	**No**
Maintenance of earthwork/embankment	○	○
Reworking shoulders	○	○
Barrier wall or traffic separator	○	○
Milling and removal	○	○
Resurfacing	○	○
Repair of concrete pavement	○	○
Crack filling	○	○
Pot filling	○	○
Surface treatment	○	○
Waterproofing/sealing	○	○
Sidewalks repair and maintenance	○	○
Riprap maintenance	○	○
Resetting guardrail/fencing	○	○
Painting stripes/pavement markers	○	○
Landscaping/grassing/sodding	○	○
Highway signing for maintenance works	○	○
Traffic signals maintenance	○	○
Highway lighting system—repair and maintenance	○	○
Bridge decks rehabilitation and maintenance	○	○
Drainage structures maintenance and rehabilitation	○	○
Sweeping and cleanup	○	○

Page 2 - Question 6 - Open Ended - One Line

Please specify any additional maintenance tasks your agency usually performs during nighttime operations which are not listed in the previous question.

Page 2 - Question 7 - Rating Scale - Matrix

How important do you feel about the following advantages of performing nighttime construction?

	Not important at all	**Somewhat important**	**Very important**	**Extremely important**
Less delay and congestion	○	○	○	○
Lower impact on surrounding business	○	○	○	○
More freedom to plan lane closures	○	○	○	○
Longer working hours	○	○	○	○
Less air pollution	○	○	○	○

Page 2 - Question 8 - Open Ended - One Line

Please specify any additional advantages of performing nighttime construction which are not listed in the previous question.

Page 3 - Question 9 - Rating Scale - Matrix

How important do you feel about the following concerns/disadvantages of performing nighttime construction?

	Not important at all	**Somewhat important**	**Very important**	**Extremely important**
Visibility problems	○	○	○	○
Higher worker rate accidents	○	○	○	○
Higher traffic accident rates	○	○	○	○
Noise	○	○	○	○
Higher construction costs	○	○	○	○
Inferior work quality	○	○	○	○
Decreased productivity	○	○	○	○
Worker and equipment scheduling problems	○	○	○	○
Materials availability problems	○	○	○	○
Equipment maintenance problem	○	○	○	○

Page 3 - Question 10 - Open Ended - One Line

Please specify any additional concerns/disadvantages of performing nighttime construction which are not listed in the previous question.

Page 3 - Question 11 - Yes or No

Does your agency have nighttime lane closure policies?

- ○ Yes
- ○ No
- ○ If yes, please provide sources name (website/others)

....

Thank You Page

Thank you for completing the questionnaire.

If you have any additional comments, please contact:

Jennifer S. Shane, Ph.D.
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498 Town Engineering
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jsshane@iastate.edu
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Fax: 515.294.3845

Screen Out Page

Thank you for your willingness to participate, however, we are looking for DOTs that perform nighttime construction.

Over Quota Page

Thank you for your willingness to participate, however, this survey is now closed.

Survey Closed Page

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APPENDIX C: PHASE I SURVEY 2-QUALITY IMPACTS OF NIGHTTIME CONSTRUCTION

Nighttime Construction - 2nd Survey (Part A: Quality & Inspectability)

Created: August 14 2009, 11:00 AM
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National Cooperative Highway Research Program (NCHRP)

Project 10-78
Nighttime Construction Impacts on Safety, Quality, and Productivity

Page 1 - Heading

Quality and Inspectability

Page 1 - Question 1 - Open Ended - One or More Lines with Prompt

Please provide your information below:

✎ Name ....
✎ Current Position ....
✎ Agency ....
✎ Phone Number ....
✎ Email ....
✎ Years of experience with DOT ....
✎ Years of experience dealing with nighttime construction ....

Page 1 - Question 2 - Yes or No

Based on your experience, do you think nighttime work significantly impacts construction quality?

○ Yes
○ No

Page 1 - Question 3 - Rating Scale - Matrix

Identify the impact on quality for each activity completed during nighttime construction activities.

	Not done at night	Highly reduced quality	Reduced (lesser) quality	Same quality	Increased (better) quality	Highly increased quality
Concrete sawing	○	○	○	○	○	○
Milling and removal	○	○	○	○	○	○
Bituminous surfaces and pavements	○	○	○	○	○	○
Repair of concrete pavement	○	○	○	○	○	○
Resurfacing	○	○	○	○	○	○
Bridge Construction	○	○	○	○	○	○
Bridge decks rehab and maintenance	○	○	○	○	○	○
Shoulders: bituminous and Portland Cement Concrete	○	○	○	○	○	○
Pot hole filling/ crack filling	○	○	○	○	○	○
Highway signing	○	○	○	○	○	○
Waterproofing/sealing	○	○	○	○	○	○
Pavement marking: striping & markers	○	○	○	○	○	○
Electrical wiring and cables	○	○	○	○	○	○
Sweeping and cleanup	○	○	○	○	○	○
Culverts and sewers	○	○	○	○	○	○
Surface Treatment	○	○	○	○	○	○
Drainage structures	○	○	○	○	○	○
Reworking shoulders	○	○	○	○	○	○
Sub-base and base course	○	○	○	○	○	○
Maintenance of earthwork/embankment	○	○	○	○	○	○
Concrete pavement and sidewalks	○	○	○	○	○	○
Drainage structures maintenance & rehabilitation	○	○	○	○	○	○
Electrical poles/lighting/traffic signals	○	○	○	○	○	○
Sidewalks repair & maintenance	○	○	○	○	○	○
Subgrade	○	○	○	○	○	○
Earthwork: excavation / embankment /backfill	○	○	○	○	○	○
Guardrail and fences	○	○	○	○	○	○
Erosion control: riprap/ditch lining	○	○	○	○	○	○
Landscaping: seeding/mulch/sodding/planting	○	○	○	○	○	○

Page 1 - Question 4 - Open Ended - One Line

Please specify any additional impacts on quality for each activity completed during nighttime construction that are not listed in the previous question.

Page 2 - Question 5 - Yes or No

Are formal inspections of the nighttime work zone performed routinely?

- ○ Yes
- ○ No

Page 2 - Question 6 - Rating Scale - Matrix

Identify the impact on quality of nighttime construction for each of the following factors:

	Highly reduced quality	**Reduced (lesser) quality**	**Same quality**	**Increased (better) quality**	**Highly increased quality**
Cooler temperature at night	○	○	○	○	○
Longer working hours at night	○	○	○	○	○
Lighting	○	○	○	○	○
Less interference of traffic	○	○	○	○	○
Quicker material deliveries	○	○	○	○	○
Allow more lanes to be closed for nighttime work	○	○	○	○	○
Increase durations of closed lanes	○	○	○	○	○
Good effective communication among agency personnel, contract manager & field staff	○	○	○	○	○
Availability and supply of materials and spare parts	○	○	○	○	○

Page 3 - Question 7 - Yes or No

Does your agency have a specification for nighttime construction?

- ○ Yes [Skip to 4]
- ○ No [Skip to 5]
- ○ If yes, please provide sources name (website/others)

Page 4 - Question 8 - Yes or No

Do the specifications for nighttime construction quality differ from the daytime construction?

- ○ Yes
- ○ No

Page 5 - Question 9 - Open Ended - One Line

How is the quality testing of nighttime construction is being done by your agency?

Page 5 - Question 10 - Yes or No

Are there any innovative methods of quality control being applied by your agency when performing nighttime construction?

○ Yes
○ No
○ If yes, please specify

Thank You Page

Thank you for completing the questionnaire.

If you have any additional comments, please contact:

Jennifer S. Shane, Ph.D.
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498 Town Engineering
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jsshane@iastate.edu
Phone: 515.294.1703
Fax: 515.294.3845

Screen Out Page

Thank you for your willingness to participate, however, we are looking for DOTs that perform nighttime construction.

Over Quota Page

Thank you for your willingness to participate, however, this survey is now closed.

Survey Closed Page

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APPENDIX D: PHASE I SURVEY 2-SAFETY IMPACTS OF NIGHTTIME CONSTRUCTION

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Nighttime Construction - 2nd Survey (Part B: Safety)

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National Cooperative Highway Research Program (NCHRP)

Project 10-78
Nighttime Construction Impacts on Safety, Quality, and Productivity

Page 1 - Heading

Safety

Page 1 - Question 1 - Open Ended - One or More Lines with Prompt

Please provide your information below:

✎ Name ....
✎ Current Position ....
✎ Agency ....
✎ Phone Number ....
✎ Email ....
✎ Years of experience with DOT ....
✎ Years of experience dealing with nighttime construction ....

Page 1 - Question 2 - Yes or No

Are construction related accidents more likely to occur in nighttime work zones?

○ Yes
○ No

Page 1 - Question 3 - Rating Scale - Matrix

Which of the following traffic accidents/ crashes are more likely to occur in nighttime work zones?

	Yes	No
Head-on collision	○	○
Rear impacts	○	○
Angle/side impacts	○	○
Roll-overs	○	○

Page 1 - Question 4 - Open Ended - One Line

Please specify any additional traffic crashes/accidents that you think are more likely to occur in nighttime work zones that are not listed in the previous question.

Page 2 - Question 5 - Rating Scale - Matrix

How much do you think the following contribute to the rate of traffic accidents at night?

	High contribution	Mild contribution	No contribution
Reduced visibility	○	○	○
Driver's drowsiness	○	○	○
Alcohol use	○	○	○

Page 2 - Question 6 - Open Ended - One Line

Please specify any additional factors that you think contribute to the rate of traffic accidents at night that are not listed in the previous question.

Page 3 - Question 7 - Rating Scale - Matrix

How much do you think the following construction accidents are more likely to occur in nighttime work zones?

	High contribution	Mild contribution	No contribution
Run off the road	○	○	○
Sideswipe	○	○	○
Overturn	○	○	○
Work zone intrusion	○	○	○

Page 3 - Question 8 - Open Ended - One Line

Please specify any additional construction accidents that you think are more likely to occur in nighttime work zones that are not listed in the previous question.

Page 4 - Question 9 - Yes or No

Does your agency have any statistics of nighttime work-related accidents in your State?

- ○ Yes
- ○ No
- ○ If yes, please provide sources name (website/others)

Page 4 - Question 10 - Open Ended - One Line

Please identify any differences, if any, in safety measures for the travelling public taken in nighttime activities that are not taken with daytime work zone activities.

Page 4 - Question 11 - Rating Scale - Matrix

Does your agency's use of the following methods to address work zone safety issues differ between nighttime and daytime construction?

	Not used at all	**Yes**	**No**
Toolbox talk	○	○	○
News coverage	○	○	○
Commercials and advertisements	○	○	○
Safety inspections	○	○	○
Work zone drive through	○	○	○

Page 4 - Question 12 - Open Ended - One Line

Please specify any additional methods that your agency frequently uses to address safety issues in nighttime construction that are not listed in the previous question.

Page 5 - Question 13 - Rating Scale - Matrix

Based on your experience, please rate the following item that you think would better improve nighttime construction work zone safety.

	Not important at all	**Somewhat important**	**Very important**	**Extremely important**
Increase Cone/Drum Taper Lengths (where applicable)	○	○	○	○
Routine Maintenance of Traffic Control Device	○	○	○	○
Decrease Cone/Drum Taper Lengths (where applicable)	○	○	○	○
Spacing of cones/drums on tapers and/or tangents use of lighting	○	○	○	○
Inspection of Traffic Control Devices Prior to Use	○	○	○	○
Increase of On-Site Law Enforcement	○	○	○	○
Review of Traffic Control Plans	○	○	○	○
Review of Incident Management Plans (e.g., Emergency Procedure)	○	○	○	○
Proper Training of Traffic Control Setup & Breakdowns	○	○	○	○
Increase in Public Awareness	○	○	○	○

Page 5 - Question 14 - Choice - One Answer (Bullets)

Based on the following scale, how safe do you feel working during nighttime?

○ Not safe at all
○ Somewhat safe
○ Neutral
○ Mostly safe
○ Completely safe

Page 6 - Question 15 - Rating Scale - Matrix

Does your agency's use of the following methods to address work zone safety issues differ between nighttime and daytime construction?

	Not used at all	Yes	No
Pre-job Planning	○	○	○
Employee Safety Training	○	○	○
Safety Incentives Program	○	○	○
Substance and Alcohol Program	○	○	○
Proper Usage of Lighting	○	○	○
Role of Law Enforcement on Site	○	○	○
Use of Personal Protective Equipment (PPE)	○	○	○
Safety Meetings	○	○	○
Accident and near miss investigations	○	○	○
Traffic Control Plan	○	○	○

Page 6 - Question 16 - Rating Scale - Matrix

The following are the safety techniques related to nighttime project planning and implementation. (Use the scale below to rate how important do you feel these factors are towards the safety of the workers)

	Not important at all	Somewhat important	Very important	Extremely important
Pre-job Planning	○	○	○	○
Employee Safety Training	○	○	○	○
Safety Incentives Program	○	○	○	○
Substance and Alcohol Program	○	○	○	○
Proper Usage of Lighting	○	○	○	○
Role of Law Enforcement on Site	○	○	○	○
Use of Personal Protective Equipment (PPE)	○	○	○	○
Safety Meetings	○	○	○	○
Accident and near miss investigations	○	○	○	○
Traffic Control Plan	○	○	○	○

Page 6 - Question 17 - Yes or No

Based on your knowledge and experience, do you think construction equipment inside the work area causes as many accidents as through traffic during the nighttime operations?

○ Yes
○ No

Page 7 - Question 18 - Yes or No

Does your agency have safety guidelines for nighttime construction?

- ○ Yes
- ○ No
- ○ If yes, please provide sources name (website/others)

Page 7 - Question 19 - Yes or No

Are there any innovative safety methods being applied by your agency when performing nighttime construction?

- ○ Yes
- ○ No
- ○ If yes, please specify

Thank You Page

Thank you for completing the questionnaire.

If you have any additional comments, please contact:

Jennifer S. Shane, Ph.D.
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498 Town Engineering
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jsshane@iastate.edu
Phone: 515.294.1703
Fax: 515.294.3845

Screen Out Page

Thank you for your willingness to participate, however, we are looking for DOTs that perform nighttime construction.

Over Quota Page

Thank you for your willingness to participate, however, this survey is now closed.

Survey Closed Page

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APPENDIX E: PHASE I SURVEY 2-CONSTRUCTION NUISANCES

Nighttime Construction - 2nd Survey (Part C: Nuisances)

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National Cooperative Highway Research Program (NCHRP)

Project 10-78
Nighttime Construction Impacts on Safety, Quality, and Productivity

Page 1 - Heading

Nuisances

Page 1 - Question 1 - Open Ended - One or More Lines with Prompt

Please provide your information below:

- Name ....
- Current Position ....
- Agency ....
- Phone Number ....
- Email ....
- Years of experience with DOT ....
- Years of experience dealing with nighttime construction ....

Page 1 - Question 2 - Rating Scale - Matrix

Rate the following items as sources of nighttime construction nuisances.

	None	Minor	Moderate	Major
Noise	○	○	○	○
Vibration	○	○	○	○
Dust	○	○	○	○
Light	○	○	○	○
Emission of greenhouse gases	○	○	○	○

Page 1 - Question 3 - Open Ended - One Line

Please specify any additional sources of nighttime construction nuisances that are not listed in the previous question.

Page 2 - Question 4 - Yes or No

Does your agency use specific criteria from local noise ordinances in place for the level of noise allowed in the work zone, and varying with distance from it?

○ Yes
○ No [Skip to 4]

Page 3 - Question 5 - Choice - One Answer (Bullets)

Please select the level of noise allowed by your agency in the work zone.

○ Lower that 40 dBA
○ 41 – 60 dBA
○ c61 – 85 dBA
○ Other, please specify

Page 4 - Question 6 - Yes or No

Does your agency uses specific noise control strategies and methods to minimize the noise during nighttime operations?

○ Yes
○ No

Page 4 - Question 7 - Rating Scale - Matrix

What are the noise control strategies that your agency uses to minimize the noise during nighttime operations?

	Yes	**No**
Source control	○	○
Transmission path control	○	○
Receptor noise control	○	○

Page 4 - Question 8 - Open Ended - One Line

Please specify any additional noise control strategies that your agency uses to minimize the noise during nighttime operations that are not listed in the previous question.

Page 5 - Question 9 - Rating Scale - Matrix

Which of the following noise mitigation measures does your agency require/provide?

	Yes	No
Noise barriers / curtains	○	○
Acoustical window treatments	○	○
Off-sites mitigation policy	○	○

Page 5 - Question 10 - Open Ended - One Line

Please specify any additional noise mitigation measures that your agency requires/provide, which are not listed in the previous question.

Page 5 - Question 11 - Yes or No

Does your agency exercise Noise Control Program for nighttime operations?

○ Yes
○ No

Page 6 - Question 12 - Rating Scale - Matrix

Were there any cases in which your agency received complaints on the following source of nighttime construction nuisances?

	Yes	No
Noise	○	○
Vibration	○	○
Dust	○	○
Light	○	○
Emission of greenhouse gases	○	○

Page 6 - Question 13 - Rating Scale - Matrix

How often does your agency receive complaints of the following source of nighttime construction nuisances?

	Never	Rarely	Sometimes	Usually	Always
Noise	○	○	○	○	○
Vibration	○	○	○	○	○
Dust	○	○	○	○	○
Light	○	○	○	○	○
Emission of greenhouse gases	○	○	○	○	○

Page 6 - Question 14 - Yes or No

Is there a specification for the amount of allowable glare in the construction work zone?

○ Yes
○ No [Skip to 8]

Page 7 - Question 15 - Yes or No

Does your DOT have special specifications dealing with work zone glare: a) As it affects motorist traveling through the work zone?

○ Yes
○ No

Page 7 - Question 16 - Yes or No

Does your DOT have special specifications dealing with work zone glare: b) Work zone neighbors?

○ Yes
○ No

Page 8 - Question 17 - Yes or No

Does your agency have mitigating nuisance’s guidelines for nighttime construction?

○ Yes
○ No
○ If yes, please provide sources name (website/others)

Page 8 - Question 18 - Yes or No

Are there any innovative methods of mitigating nuisances being applied by your agency when performing nighttime construction?

○ Yes
○ No
○ If yes, please specify

Thank You Page

Thank you for completing the questionnaire.

If you have any additional comments, please contact:

Jennifer S. Shane, Ph.D.
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Screen Out Page

Thank you for your willingness to participate, however, we are looking for DOTs that perform nighttime construction.

Over Quota Page

Thank you for your willingness to participate, however, this survey is now closed.

Survey Closed Page

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APPENDIX F: PHASE I SURVEY 2-COMMUNICATIONS STRATEGIES

Nighttime Construction - 2nd Survey (Part E: Communication)

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National Cooperative Highway Research Program (NCHRP)

Project 10-78
Nighttime Construction Impacts on Safety, Quality, and Productivity

Page 1 - Heading

Communication

Page 1 - Question 1 - Open Ended - One or More Lines with Prompt

Please provide your information below:

- Name
- Current Position
- Agency
- Phone Number
- Email
- Years of experience with DOT
- Years of experience dealing with nighttime construction

Page 1 - Question 2 - Rating Scale - Matrix

Does your agency's use of the following methods of communication differ from nighttime and daytime construction?

	Not used at all	**Yes**	**No**
Local news	○	○	○
Newspapers	○	○	○
Fliers	○	○	○
Notices	○	○	○
Ads	○	○	○
Website	○	○	○
ITS equipment	○	○	○
Toll free number	○	○	○
Local news	○	○	○

Page 1 - Question 3 - Rating Scale - Matrix

What are the modes of communications used to inform the public about the status of nighttime construction work?

	Yes	No
Local news	○	○
Newspapers	○	○
Fliers	○	○
Notices	○	○
Ads	○	○
Website	○	○
ITS equipment	○	○
Toll free number	○	○
Local news	○	○

Page 1 - Question 4 - Open Ended - One Line

Please specify any additional modes of communications used to inform the public about the status of nighttime construction work that are not listed in the previous question.

Page 1 - Question 5 - Rating Scale - Matrix

What are the types of information relayed to the public concerning nighttime construction work?

	Yes	No
Lane Closures	○	○
Delays	○	○
Speeds	○	○
Lengths	○	○
Contact information of relevant agencies	○	○

Page 1 - Question 6 - Open Ended - One Line

Please specify any additional types of information relayed to the public concerning nighttime construction work that are not listed in the previous question.

Page 2 - Question 7 - Yes or No

Does your agency have communication guidelines for nighttime construction?

○ Yes
○ No
○ If yes, please provide sources name (website/others)

Page 2 - Question 8 - Yes or No

Are there any innovative methods of communication being applied by your agency when performing nighttime construction?

○ Yes
○ No
○ If yes, please specify

Thank You Page

Thank you for completing the questionnaire.

If you have any additional comments, please contact:

Jennifer S. Shane, Ph.D.
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Screen Out Page

Thank you for your willingness to participate, however, we are looking for DOTs that perform nighttime construction.

Over Quota Page

Thank you for your willingness to participate, however, this survey is now closed.

Survey Closed Page

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APPENDIX G: PHASE I SURVEY 2-ILLUMINATION

Nighttime Construction - 2nd Survey (Part D: Illumination)

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National Cooperative Highway Research Program (NCHRP)

Project 10-78
Nighttime Construction Impacts on Safety, Quality, and Productivity

Page 1 - Heading

Illumination

Page 1 - Question 1 - Open Ended - One or More Lines with Prompt

Please provide your information below:

Name ....
Current Position ....
Agency ....
Phone Number ....
Email ....
Years of experience with DOT ....
Years of experience dealing with nighttime construction ....

Page 1 - Question 2 - Rating Scale - Matrix

Which of the following factors associated with lighting provisions do you think influence task illumination levels:

	Yes	No
Work zone geometry and size	○	○
Orientation of lighting equipment	○	○
Power and type of lamps	○	○
Required lighting uniformity	○	○
Glare avoidance	○	○

Page 1 - Question 3 - Open Ended - One Line

Please specify any additional sources of lighting provisions do you think influence task illumination levels that are not listed in the previous question.

Page 1 - Question 4 - Choice - One Answer (Bullets)

How do you consider the required lighting conditions on nighttime construction projects in your state?

- ○ Poor
- ○ Fair
- ○ Good
- ○ Very good
- ○ Excellent

Page 2 - Question 5 - Rating Scale - Matrix

Which of the following criteria does your agency use for roadway lighting design?

	Yes	**No**
Luminance Lighting	○	○
Horizontal Illumination	○	○

Page 2 - Question 6 - Open Ended - One Line

Please specify any additional criteria that your agency uses for roadway lighting design that are not listed in the previous question.

Page 2 - Question 7 - Yes or No

Are there any preferred luminaires types and brands for use in temporary roadway lighting arrangements?

- ○ Yes
- ○ No
- ○ If yes, please specify

Page 2 - Question 8 - Yes or No

Are there any specifications in the special conditions of the DOT contracts for temporary lighting arrangements?

- ○ Yes
- ○ No

Page 3 - Question 9 - Yes or No

Does the DOT inspect the lighting arrangements on work zones before construction starts?

- ○ Yes
- ○ No

Page 3 - Question 10 - Yes or No

Do you have specific lighting requirements for different construction tasks?

○ Yes
○ No [Skip to 5]
○ If yes, please provide sources name (website/others)

Page 4 - Question 11 - Rating Scale - Matrix

What are the factors that influence the illuminance requirements for nighttime operations?

	Yes	**No**
Worker capabilities and skill	○	○
Work zone conditions and locations	○	○
Equipment use	○	○
Task-physical difficulty	○	○
Task-quality requirements	○	○
Level of inspection needed	○	○
Other tasks taking place	○	○
Availability and cost of lighting equipment	○	○

Page 4 - Question 12 - Yes or No

Are contractors required to provide lighting plans prior to starting nighttime construction activities?

○ Yes
○ No

Page 4 - Question 13 - Choice - One Answer (Bullets)

If contractors provide lighting plans for nighttime construction, does the DOT approve these plans prior to implementation?

○ Not applicable
○ Yes
○ No

Page 5 - Question 14 - Yes or No

Does your agency have lighting guidelines for nighttime construction?

○ Yes
○ No
○ If yes, please provide sources name (website/others)

Page 5 - Question 15 - Yes or No

Are there any innovative methods of lighting being applied by your agency when performing nighttime construction?

○ Yes
○ No
○ If yes, please specify

Thank You Page

Thank you for completing the questionnaire.

If you have any additional comments, please contact:

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Screen Out Page

Thank you for your willingness to participate, however, we are looking for DOTs that perform nighttime construction.

Over Quota Page

Thank you for your willingness to participate, however, this survey is now closed.

Survey Closed Page

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APPENDIX H: PHASE I SURVEY 2-PRODUCTIVITY IMPACTS OF NIGHTTIME CONSTRUCTION

Nighttime Construction - 2nd Survey (Part F: Productivity)

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National Cooperative Highway Research Program (NCHRP)

Project 10-78
Nighttime Construction Impacts on Safety, Quality, and Productivity

Page 1 - Heading

Productivity

Page 1 - Question 1 - Open Ended - One or More Lines with Prompt

Please provide your information below:

Name ....
Current Position ....
Agency ....
Phone Number ....
Email ....
Years of experience with DOT ....
Years of experience dealing with nighttime construction ....

Page 1 - Question 2 - Yes or No

Does nighttime work significantly impact construction productivity?

○ Yes
○ No

Page 1 - Question 3 - Yes or No

In your opinion, do you think higher productivity levels will be achieved by performing nighttime construction?

○ Yes
○ No

Page 1 - Question 4 - Rating Scale - Matrix

In your opinion, do the following nighttime factors impact productivity of nighttime operations?

	Very negative impact	**Negative impact**	**Positive impact**	**Very positive impact**
Less interference of traffic	○	○	○	○
Quicker material deliveries	○	○	○	○
Allow more lanes to be closed for nighttime work	○	○	○	○
Increase durations of closed lanes	○	○	○	○
Good effective communication among agency personnel, contract manager & field staff	○	○	○	○
Availability and supply of materials and spare parts	○	○	○	○
Longer working hours at night	○	○	○	○

Page 1 - Question 5 - Open Ended - One Line

Please specify any additional factors that impact the productivity of nighttime operations which are not listed in the previous question. Please be sure to indicate if the impact is positive or negative.

Page 1 - Question 6 - Yes or No

Does your agency monitor/measure contractor productivity?

○ Yes
○ No [Skip to 3]

Page 2 - Question 7 - Open Ended - One Line

How is the productivity being measured by your agency?

Page 3 - Question 8 - Yes or No

Is the productivity measurement during daytime different than nighttime?

○ Yes
○ No

Page 3 - Question 9 - Rating Scale - Matrix

Rate the impact of nighttime work on the following construction activities:

	Not done at night	Very negative impact	Negative impact	Positive impact	Very positive impact
Concrete sawing	○	○	○	○	○
Milling and removal	○	○	○	○	○
Bituminous surfaces and pavements	○	○	○	○	○
Repair of concrete pavement	○	○	○	○	○
Resurfacing	○	○	○	○	○
Bridge Construction	○	○	○	○	○
Bridge decks rehab and maintenance	○	○	○	○	○
Shoulders: bituminous and Portland cement concrete	○	○	○	○	○
Pot hole filling/ crack filling	○	○	○	○	○
Highway signing	○	○	○	○	○
Waterproofing/sealing	○	○	○	○	○
Pavement marking: striping & markers	○	○	○	○	○
Electrical wiring and cables	○	○	○	○	○
Sweeping and cleanup	○	○	○	○	○
Culverts and sewers	○	○	○	○	○
Surface Treatment	○	○	○	○	○
Drainage structures	○	○	○	○	○
Reworking shoulders	○	○	○	○	○
Sub-base and base course	○	○	○	○	○
Maintenance of earthwork/embankment	○	○	○	○	○
Concrete pavement and sidewalks	○	○	○	○	○
Drainage structures maintenance & rehabilitation	○	○	○	○	○
Electrical poles/lighting/traffic signals	○	○	○	○	○
Sidewalks repair & maintenance	○	○	○	○	○
Subgrade	○	○	○	○	○
Earthwork: excavation / embankment / backfill	○	○	○	○	○
Guardrail and fences	○	○	○	○	○
Erosion control: riprap/ ditch lining	○	○	○	○	○
Landscaping: seeding/mulch/sodding/planting	○	○	○	○	○

Page 3 - Question 10 - Open Ended - One Line

Please indicate any additional construction activities that have impact of nighttime work which are not listed in the previous question.

Page 4 - Question 11 - Yes or No

Does your agency have productivity guidelines for nighttime construction?

○ Yes
○ No
○ If yes, please provide sources name (website/others)

Page 4 - Question 12 - Yes or No

Are there any innovative methods of productivity being applied by your agency when performing nighttime construction?

○ Yes
○ No
○ If yes, please specify

Thank You Page

Thank you for completing the questionnaire.

If you have any additional comments, please contact:

Jennifer S. Shane, Ph.D.
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Screen Out Page

Thank you for your willingness to participate, however, we are looking for DOTs that perform nighttime construction.

Over Quota Page

Thank you for your willingness to participate, however, this survey is now closed.

Survey Closed Page

(Standard - Zoomerang branding)

APPENDIX I: PHASE I SURVEY 2-WORK ZONE PLANNING RISK ANALYSIS

Nighttime Construction - 2nd Survey (Part G: Risk/ Work Zone)

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National Cooperative Highway Research Program (NCHRP)

Project 10-78
Nighttime Construction Impacts on Safety, Quality, and Productivity

Page 1 - Heading

Risk / Work Zone

Page 1 - Question 1 - Open Ended - One or More Lines with Prompt

Please provide your information below:

- Name ____________________
- Current Position ____________________
- Agency ____________________
- Phone Number ____________________
- Email ____________________
- Years of experience with DOT ____________________
- Years of experience dealing with nighttime construction ____________________

Page 1 - Question 2 - Yes or No

Is there any formal process of nighttime construction risk analysis in place use by your agency?

○ Yes
○ No

Page 1 - Question 3 - Rating Scale - Matrix

Please rate the significance of the following risks in nighttime work zone traffic control:

	Not important at all	Somewhat important	Very important	Extremely important
More impaired drivers	○	○	○	○
Higher speeds and lower volumes	○	○	○	○
Insufficient lighting for workers	○	○	○	○
Noise restrictions	○	○	○	○
Worker fatigue	○	○	○	○
Drivers who do not expect night work zones	○	○	○	○
Glare	○	○	○	○
Poor visibility	○	○	○	○

Page 1 - Question 4 - Open Ended - One Line

Please specify any additional risks in nighttime work zone traffic control which are not listed in the previous question.

Page 2 - Question 5 - Open Ended - One Line

Please specify any risk assessment and management programs that your agency uses for nighttime construction. Please provide sources name, i.e., website/others (if any)

Page 2 - Question 6 - Rating Scale - Matrix

Which of the following project-specific documents does your agency use for risk identification?

	Yes	No
Project description	○	○
Work breakdown structure	○	○
Cost estimate	○	○
Design and construction schedule	○	○
Procurement plan	○	○
Listing of team's issues and concerns	○	○

Page 2 - Question 7 - Open Ended - One Line

Please specify any additional project-specific documents that your agency uses for risk identification which are not listed in the previous question.

Page 3 - Question 8 - Rating Scale - Matrix

Which of the following programmatic documents does your agency use for risk identification?

	Yes	No
Historic data	○	○
Checklists	○	○
Final project reports	○	○
Risk response plans	○	○
Organized lessons learned	○	○
Published commercial databases	○	○
Academic studies	○	○

Page 3 - Question 9 - Open Ended - One Line

Please specify any additional programmatic documents that your agency uses for risk identification which are not listed in the previous question.

Page 3 - Question 10 - Rating Scale - Matrix

Which of the following risk identification techniques does your agency use for risk identification?

	Yes	No
Brainstorming	○	○
Scenario planning	○	○
Expert interviews	○	○
Nominal group methods	○	○
Delphi methods	○	○
Crawford slip methods	○	○
Influence or risk diagramming	○	○

Page 3 - Question 11 - Open Ended - One Line

Please specify any additional risk identification techniques that your agency uses for risk identification which are not listed in the previous question.

Page 4 - Question 12 - Rating Scale - Matrix

Please rate the importance of the following nighttime work zone risk mitigation methods using traffic control:

	Not important at all	Somewhat important	Very important	Extremely important
Improving visibility of workers	○	○	○	○
Using drums in taper	○	○	○	○
Having a detailed lighting plan	○	○	○	○
Using the police	○	○	○	○
Maintaining devices	○	○	○	○
Using PCMS with specific messages	○	○	○	○
Using fluorescent orange signs	○	○	○	○
Having higher fines for violations	○	○	○	○
Requiring noise variance and mitigation measures	○	○	○	○
Using flashing beacons on leading sign	○	○	○	○
Using flashing speed limits w/lower speeds on trailer	○	○	○	○
Working where there is highway lighting	○	○	○	○
Arranging for delivery of materials	○	○	○	○
Illuminating flagger station	○	○	○	○
Providing buffer lane	○	○	○	○
Providing proper delineation	○	○	○	○
Evaluating each project for changes	○	○	○	○
Using a smaller spacing of channelizing devices	○	○	○	○
Using amber revolving lights and 4-way flashers on work vehicles	○	○	○	○
Requiring vehicle warning beacons and reflective tape	○	○	○	○
Taking care to avoid glare	○	○	○	○
Having spare lighting units on hand	○	○	○	○
Requiring Type A flashing light on first two channelizing devices	○	○	○	○
Requiring Type B flashing lights for isolated signs	○	○	○	○

Page 4 - Question 13 - Open Ended - One Line

Please specify any additional nighttime work zone risk mitigation methods using traffic control that are not listed in the previous question.

Page 5 - Question 14 - Yes or No

Does your agency have risk analysis guidelines for nighttime construction?

○ Yes
○ No
○ If yes, please provide sources name (website/others)

Page 5 - Question 15 - Yes or No

Are there any innovative methods of risk analysis being applied by your agency when performing nighttime construction?

○ Yes
○ No
○ If yes, please specify

Thank You Page

Thank you for completing the questionnaire.

If you have any additional comments, please contact:

Jennifer S. Shane, Ph.D.
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498 Town Engineering
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Screen Out Page

Thank you for your willingness to participate, however, we are looking for DOTs that perform nighttime construction.

Over Quota Page

Thank you for your willingness to participate, however, this survey is now closed.

Survey Closed Page

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APPENDIX J: PHASE I SURVEY 2-NIGHTTIME CONSTRUCTION COST DIFFERENTIALS

Nighttime Construction - 2nd Survey (Part H: Cost)

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National Cooperative Highway Research Program (NCHRP)

Project 10-78
Nighttime Construction Impacts on Safety, Quality, and Productivity

Page 1 - Heading

Cost

Page 1 - Question 1 - Open Ended - One or More Lines with Prompt

Please provide your information below:

- Name ....
- Current Position ....
- Agency ....
- Phone Number ....
- Email ....
- Years of experience with DOT ....
- Years of experience dealing with nighttime construction ....

Page 1 - Question 2 - Yes or No

Has your agency compared the cost between daytime and nighttime construction?

○ Yes
○ No

Page 1 - Question 3 - Rating Scale - Matrix

Please indicate the impact of nighttime work on costs compared to work completed in the daytime.
(If your answer in Question 1 is no, then use your engineering judgment to answer this question)

	Much more expensive	More expensive	No change	Less expensive	Much less expensive
Construction cost	○	○	○	○	○
Design cost	○	○	○	○	○
Agency administration cost	○	○	○	○	○
Travelling public cost	○	○	○	○	○

Page 1 - Question 4 - Rating Scale - Matrix

Indicate the change on cost completing the following activities at night as compared to daytime construction.

	Not done at night	Large decrease in cost	Decrease in cost	No change / No impact	Increase in cost	Large increase in cost
Removal of existing pavement	○	○	○	○	○	○
Regular excavation	○	○	○	○	○	○
Bituminous material – prime coat	○	○	○	○	○	○
Bituminous material – tack coat	○	○	○	○	○	○
Milling existing asphalt pavement	○	○	○	○	○	○
Concrete miscellaneous	○	○	○	○	○	○
Asphalt concrete friction course –including bitumen	○	○	○	○	○	○
Removal of existing pavement	○	○	○	○	○	○

Page 1 - Question 5 - Open Ended - One Line

Please specify any additional construction activities that indicate the change of cost at night as compared to daytime construction which are not listed in the previous question.

....

Page 2 - Question 6 - Rating Scale - Matrix

In your opinion, do the following construction cost impact nighttime operations?

	Very negative impact	Negative impact	Positive impact	Very positive impact
Lighting	○	○	○	○
Additional traffic control	○	○	○	○
Inspection	○	○	○	○
Labor premiums	○	○	○	○
Overtime	○	○	○	○
Increase material costs	○	○	○	○

Page 2 - Question 7 - Open Ended - One Line

Please specify any additional construction costs that are attributed to nighttime work which are not listed in the previous question

....

Page 2 - Question 8 - Rating Scale - Matrix

Do you think the following aspects help in decreasing the cost of nighttime construction?

	Yes	No
Reduce traffic interference	○	○
Improve flexibility design	○	○

Page 2 - Question 9 - Open Ended - One Line

Please specify any additional aspects that help in decreasing the cost of nighttime construction which are not listed in the previous question

Page 3 - Question 10 - Yes or No

Does your agency have nighttime cost control guidelines for nighttime construction?

○ Yes
○ No
○ If yes, please provide sources name (website/others)

Page 3 - Question 11 - Yes or No

Are there any innovative methods of minimizing nighttime construction cost being applied by your agency when performing nighttime construction?

○ Yes
○ No
○ If yes, please specify

Thank You Page

Thank you for completing the questionnaire.

If you have any additional comments, please contact:

Jennifer S. Shane, Ph.D.
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Ames, IA 50011
jsshane@iastate.edu
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Survey Closed Page

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APPENDIX K: PHASE I LINKS PROVIDED FROM SURVEYS

Survey 1- Guidelines or Specifications for Performing Nighttime Construction

1	There is no published guidelines for when to perform night work, that is based on traffic ques and the location of the project. There are lighting specification in our Standard Specification at www.dotd.la.gov under publications Section 105.20
2	http://www.dot.il.gov/desenv/pdf/80208.pdf
3	Specification states that if work is performed at night, the Contractor shall provide adequate artificial lighting.
4	nothing specific to night time other than appropriate lighting
5	Special Provision Section 150-Traffic Control. Found on GDOT's external website under The Source
6	http://www.iowadot.gov/specifications/dev_specs/DS-01116.pdf
7	http://www.wsdot.wa.gov/Publications/Manuals/M41-01.htm http://www.wsdot.wa.gov/Publications/Manuals/M22-01.htm http://www.wsdot.wa.gov/Publications/Manuals/M41-10.htm http://www.wsdot.wa.gov/Publications/Manuals/M51-02.htm
8	www.mygdot.dot.ga.gov then go to doing business/the source/shelf special provisions/section 150 traffic control
9	Only to follow lighting criteria from NCHRP report
10	http://www.dot.state.co.us/DesignSupport/Construction/2005SpecsBook/2005index.htm
11	lighting requirements. Page 607, section 812 and page 398 section 706 http://mdotwas1.mdot.state.mi.us/public/specbook/
12	Standard specifications - Section 1-10.3 http://www.wsdot.wa.gov/Publications/Manuals/M41-10.htm Project specific specifications are also used.
13	Specifications are project specific and usually are worded as time restrictions for lane closures.
14	Our traffic control is section 600 http://www.scdot.org/doing/StandardSpecifications/pdfs/2007_full_specbook.pdf
15	Specifications are the same whether day or night. Go to http://www.ct.gov/dot/cwp/view.asp?a=3199&q=259402
16	http://roadwaystandards.dot.wi.gov/standards/fdm/11-50-030.pdf
17	http://www.udot.utah.gov/main/f?p=100:pg:0:::1:T,V:1925, see specification sections: 00555 Part 1.12, 01355 Part 1.11, and 01554 Part 2.2.
18	https://www.nysdot.gov/main/business-center/engineering/specifications
19	Not much, but there is information in this specification: http://www.modot.org/business/standards_and_specs/Sec0616.pdf
20	Section 624 http://www.nevadadot.com/business/contractor/standards/documents/2001StandardSpecifications.pdf

Survey 2-General-Nighttime Lane Closure Policies

1	http://www.wsdot.wa.gov/publications/manuals/fulltext/M22-01/1010.pdf

Survey 2-Quality-Specifications for Nighttime Construction

1	Standard Specification 619.24 https://www.nysdot.gov/main/business-center/engineering/specifications/english-spec-repository/section600.pdf
2	Standard Specifications for Highways and Bridges www.mhd.state.ma.us/

Survey 2-Safety-Guidelines for Nighttime Construction

1	http://www.wsdot.wa.gov/publications/manuals/fulltext/M22-01/1010.pdf
2	Yes and no. We have only one guideline/specification for lighting of nighttime paving operations, but it does not apply to all work zones/operations in place a nighttime.
3	Delaware Manual on Uniform Traffic Control Devices (www.delaware.gov)
4	NCHRP Report 476
5	Highway Design Manual Chapter 16
6	Refer to NCHRP Report 476.

Survey 2-Illumination-Guidelines for Nighttime Construction

1	See earlier question specification reference.
2	http://www.wsdot.wa.gov/publications/manuals/fulltext/M22-01/1040.pdf
3	Delaware Manual on Uniform Traffic Control Devices (www.deldot.gov)
4	www.dotd.la.gov Standard Specifications 105.20
5	Standard Specification §619 Highway Design Manual Chapter 16
6	Soon we will be implementing a night work zone lighting standardized special provision.
7	Average illuminate 10 ftcd Uniform ratio average to minimum 4 to 1
8	KYTC Specs

Survey 2-Illumination-Specific Lighting Requirements for Different Construction Tasks

1	Bridge Deck work involving concrete pours
2	Section 2550 of Standard Specifications: http://www.iowadot.gov/specifications/specbook/Division%2025.pdf
3	There should be enough light to accomplish the task in a safe matter.
4	www.dotd.la.gov Standard Specification Section 105.20 Nighttime Construction Operations
5	Standard Specification Section 619-3.19
6	Night time lighting for paving operations. Overhead lighting for most other work at and before the work site.
7	Refer to KYTC Specs

Survey 2-Risk-Guidelines for Nighttime Construction

1	Nighttime Road Construction Operations Synthesis of Practice

Survey 2-Cost-Guidelines for Nighttime Construction

1	It is review in TMP where the cost of night work vs. cost to the traveling public is compared.

APPENDIX L: PHASE II CASE STUDY STRUCTURED INTERVIEW QUESTIONNAIRE

NCHRP 10-78 **DATE:**____________________________

Structured Interview Questionnaire: Nighttime Case Study

CONDITIONS: This interview can either be conducted in person or via telephone. The following protocol shall be followed during its administration:

1. The questionnaire shall be sent via email to the respondent prior to the interview.
2. Two days prior to the interview, a follow-up message with the questionnaire attached will be sent to confirm the date and time of the interview.
3. To maximize the quality and quantity of information collected, the primary respondent should be encouraged to invite other members of the organization to be present during the interview. Thus, a single agency response can be formulated and recorded.
4. The interviewer will set the stage with a brief introduction that emphasizes the purpose of the research, the type of information being sought, and the ground rules for the interview.
5. Once the interviewees indicate that they understand the process at hand, the interview will commence.
6. The interviewer will read each question verbatim and then ask if the interviewee understood the question before asking the interviewee to respond.
7. Each question contains a specific response that must be obtained before moving to the next question. Once that response is obtained, the interviewer can record as text additional cogent information that may have been discussed by the interviewees in working their way to the specific response.
8. Upon conclusion of the interview, the interviewer will ask the interviewees if they have additional information that they would like to contribute and record those answers as text.
9. The interviewer will assemble a clean copy of the final interview results and return them to the interviewee for verification.

Contents

Note: Sections I-II will be asked in every interview, only portions of Section III will be asked in each interview

I. General Information

This information will be requested in every interview.

1. US state or Non-US province/state and country in which participant is located:

2. Name of Agency:

3. Type of organization:

   ☐ Public Transportation Agency ☐ Other public agency ☐ Other; Please describe:

   ☐ Highway/Road Agency
   ☐ Rail/Commuter Transit Agency
   ☐ Airport Agency
   ☐ Seaport/Marine Transportation Agency
   ☐ Other Please describe:

4. What level of authority is your agency?

   ☐ National ☐ State/Province ☐ County/City/Local ☐ Other; Please describe:

5. Does your agency use the same project management system on both nighttime and routine projects?

   ☐ Yes ☐ No Explain if necessary:

6. Does your agency conduct maintenance activities at night? Note: maintenance activities may be considered as interchangeable with construction activities.

   ☐ Yes ☐ No Explain if necessary:

II. Case Study Standard Information

This information will be requested in every interview.

Safety

Nighttime project activities can present significant hazards to both construction workers and the traveling public.

What are the methods that your agency uses to address work zone safety issues (motorized, non-motorized, workers, etc.)?

Are the precautions taken on nighttime work zones for the public driving through that are different from those for daytime?
☐ Yes ☐ No Explain if necessary:

Are the precautions taken on nighttime work zones for the workers that are different from those for daytime?
☐ Yes ☐ No Explain if necessary:

Please provide any standards, procedures, or methods for nighttime safety or a web address where we can download them:

Communications

The public does not always understand or appreciate the need for nighttime construction work; therefore, communication is a vital component of successfully accomplishing a nighttime construction project.

What method of communication does your agency use?

	Daytime	**Nighttime**
Method – Receiving information		
Hearing/Public meetings	☐	☐
Hotlines	☐	☐
Email	☐	☐
Kiosk	☐	☐
Facebook	☐	☐
Twitter	☐	☐
Other (please explain):	☐	☐
Method - Delivering information		
Press	☐	☐
Web	☐	☐
Radio	☐	☐
Other (please explain):	☐	☐

Please provide any standards, procedures, or methods for nighttime communication or a web address where we can download them:

Risk

Risks in construction work zones are numerous. These risks include vehicle intrusions into work zone resulting in workers being struck by intruding vehicles, workers struck by construction equipment, and construction equipment intrusion in operational traffic lanes.

Is there a risk management program being use by your agency in general? ☐ Yes ☐ No Explain if necessary:

What are the risk management techniques/assessments does your agency use?

Do you use any specific check lists for risk identification?

What are the innovative ways of mitigating risk/risk analysis being applied by your agency?

Please provide any standards, procedures, or methods for nighttime risk or a web address where we can download them:

Cost

In a number of studies the cost of construction has been shown to be impacted by scheduling nighttime construction operations.

Does your agency reflect the difference between nighttime and daytime costs in the following:

Activity	**Yes**	**No**
Planning Estimates	☐	☐
STIP Estimate	☐	☐
Design Estimates	☐	☐
PS&E Estimate	☐	☐
Letting and awarding a project	☐	☐
Construction Estimating (i.e. change orders)	☐	☐
Other (please explain):	☐	☐

What are the values for cost differences between daytime and nighttime (i.e., actual costs, deltas, or percentage)?

Please provide any standards, procedures, or methods for nighttime cost:

Quality

Working at night can have implications on work quality.

Do you experience differences in quality of work completed at nighttime?
☐ Yes ☐ No Explain if necessary:
If yes, how is this reflected in your projects?

Do your acceptable quality standards differ for nighttime work compared to daytime work?
☐ Yes ☐ No Explain if necessary:

Do your quality testing standards differ for nighttime work compared to daytime work?
☐ Yes ☐ No Explain if necessary:

Do your quality inspection frequencies differ for nighttime work compared to daytime work?
☐ Yes ☐ No Explain if necessary:

The effects of lower light levels on worker vision can affect quality. Different types of work are more suitable for nighttime construction.

Are there any specific activities that you prohibit during nighttime hours?
☐ Yes ☐ No
If yes, which activities?

Please provide any standards, procedures, or methods for nighttime quality (acceptability or testing procedures) or a web address where we can download them:

Productivity

Productivity is an efficiency measure that is a ratio of output of a product per labor-hour input (i.e. rate of progress or quantities installed per day). There is an intuitive correlation between nighttime work/shifts and losses in productivity.

How does nighttime construction impact any of the following activities? Are impacts considered when your agency is planning and designing the activity?

Type of Activities	**Increases Productivity**	**Decreases Productivity**	**No Impact**	**Agency Consideration**
Asphalt Paving	☐	☐	☐	
Concrete Paving	☐	☐	☐	
Bridge Pier	☐	☐	☐	
Bridge Deck	☐	☐	☐	
Pavement Marking	☐	☐	☐	
Pavement Removal	☐	☐	☐	
Grading	☐	☐	☐	
Earthmoving	☐	☐	☐	
Shoulder Work	☐	☐	☐	
Staging and Mobilization	☐	☐	☐	
Other (please explain):	☐	☐	☐	

When does your agency consider construction productivity in general for nighttime projects when completing the following activities?

Activity	**Yes**	**No**
Planning	☐	☐
Design	☐	☐
Estimating	☐	☐
Assigning resources	☐	☐
Letting and awarding a project	☐	☐
Other (please explain):	☐	☐

If yes to any of the above, how does your agency consider differences in nighttime and daytime productivity?

Activity	**Explain**
Planning	
Design	
Estimating	
Assigning resources	
Letting and awarding a project	
Other (please explain):	

Do you measure nighttime construction productivity?

☐ Yes ☐ No If yes, please explain how:

Please provide any standards for nighttime productivity monitoring:

Please provide any standards, procedures, or methods for nighttime productivity or a web address where we can download them:

Nuisances

The major nuisances associated with the nighttime construction are noise, illumination, and vibration.

Does your agency consider construction nuisances when completing the following activities?

Activity	**Yes**	**No**
Planning	☐	☐
Design	☐	☐
Bid/Contract documents	☐	☐
Assigning resources	☐	☐
Letting and awarding a project	☐	☐
Other (please explain):	☐	☐

If yes to above, do you consider differences in nighttime and daytime nuisances?

Activity	**Yes**	**No**	**Explanation**
Planning	☐	☐	
Design	☐	☐	
Bid/Contract documents	☐	☐	
Assigning resources	☐	☐	
Letting and awarding a project	☐	☐	
Other (please explain):	☐	☐	

Please provide any standards, procedures, or methods for nighttime nuisances or a web address where we can download them:

Illumination

Vision, visibility, and light pollution problems are regularly encountered during nighttime construction work. Nighttime construction activities require the creation of adequate lighting conditions.

Who selects the type of illumination for nighttime projects?
☐ Agency ☐ Contractor Please explain:

What type of illumination do contractors use on your project work zones?

Illumination Type	**Traveling public through nighttime work zone**	**Construction activities at night (for workers to see)**
Mobile Light Towers	☐	☐
Stationary Balloon Lighting	☐	☐
Equipment Mounted Balloon Lighting	☐	☐
Equipment Lighting (Headlights)	☐	☐
Portable Lighting Equipment	☐	☐
Other (please explain):	☐	☐

Do you perform inspections of nighttime lighting?
☐ Yes ☐ No If yes please explain how, including frequency:

Please provide any standards, procedures, or methods for nighttime illumination or a web address where we can download:

III. Case Study Specific Information

Only certain portions of this information will be requested in an interview, please see list below for areas of interest for this interview. Questions may be project specific or for a program.

Specific information on the following issues is requested from you:

Request	Issue	Page #
☐	Safety	169
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Safety

Nighttime project activities can cause significant hazards to both construction workers and the traveling public.

1. Does your agency conduct safety talks? ☐ Yes ☐ No Explain if necessary:
    a. If yes, how often are these talks conducted?
    b. If yes, are they regularly scheduled or ad hoc?
    c. If yes, what safety issues are talked about the most?
    d. If yes, is there any difference in talks for nighttime work compared to daytime work?
2. Does your agency require contractors perform safety talks? ☐ Yes (go to 2a) ☐ No (go to 2e) ☐ Do not know

    Explain if necessary:

    a. If yes, how often are they conducted?
    b. If yes, are they regularly scheduled or ad hoc?
    c. If yes, what safety issues are talked about the most?
    d. If yes, are there requirements about the content of nighttime talks vs. daytime talks? ☐ Yes ☐ No Explain if necessary:

   e. If no, do contractors still perform safety talks on their own? ☐ Yes ☐ No Explain if necessary:

      i. How often?

      ii. Are they regularly scheduled or ad hoc?

      iii. What safety issues are talked about the most?
      iv. Is there a difference between daytime and nighttime talks?
3. What kind of safety inspections do you use/perform for nighttime work?
4. Do you think that nighttime work is negatively or positively impacted by safety?
   a. How strong do you feel safety impacts nighttime work?

☐ Does not impact at all

☐ Somewhat impacts

☐ Neutral

☐ Quite impacts

☐ Strongly impacts

Explain if necessary:

5. Do you think that safety is negatively or positively impacted by nighttime work?
    a. How strong do you feel safety impacts nighttime work?

☐ Does not impact at all

☐ Somewhat impacts

☐ Neutral

☐ Quite impacts

☐ Strongly impacts

Explain if necessary:

6. Do you require a traffic control plan through a work zone? ☐ Yes ☐ No Explain if necessary:
    a. Does your agency develop traffic control plans or are these left to the contractor to develop?
    b. Please describe a typical traffic control plan for nighttime construction?
    c. Is a nighttime plan different from a daytime plan?
7. What are the types of personal protective equipment (PPE) that your agency uses?
    a. Do these differ for nighttime work compared to daytime work? ☐ Yes ☐ No Explain if necessary:
8. Are the precautions taken for nighttime work zone drive through different from daytime work zone drive through?

9. Do you have standards, processes, or methods to address work zone safety issues? ☐ Yes ☐ No Explain if necessary:

   a. What are the standards, processes, or methods that your agency uses to address work zone safety issues?

   b. Are these methods different for nighttime work zones? ☐ Yes ☐ No Explain if necessary:

10. What are the top causes of accidents in the work area?

Daytime	Nighttime

11. Do answers from 11 differ from none-work-zone area?

Daytime	Nighttime
☐ Yes ☐ No Explain if necessary:	☐ Yes ☐ No Explain if necessary:

12. If your agency conducts maintenance work at night, are there any safety concerns?

    ☐ Yes (go to 13a) ☐ No Explain if necessary:

   a. Do your maintenance workers have regular safety talks about nighttime work? ☐ Yes ☐ No Explain if necessary:

   b. How does nighttime maintenance work safety impact your maintenance program?

13. Are there any other issues regarding safety in nighttime work zones that you would like to discuss? ☐ Yes ☐ No

Comments:

Communications

The public does not always understand or appreciate the need for nighttime construction work; therefore, communication is an important component of successfully accomplishing a nighttime construction project.

1. Does your agency have communication guidelines specific to nighttime work? ☐ Yes ☐ No Explain if necessary:
2. What method of communication does your agency use to communicate internally?

Daytime	Nighttime

3. What method(s) of communication does your agency use to communicate with the public?

Daytime	Nighttime

4. What type(s) of information does your agency relay to the public and how?

Daytime	Nighttime

5. Do you have any innovative ways of communication? ☐ Yes ☐ No
    a. If yes, what are the innovative ways of communicating being applied by your agency? Can you provide copies or examples?

Daytime	Nighttime

6. Do you consider your communication approach for nighttime construction effective?

☐ Yes ☐ No Explain if necessary:

7. If your agency conducts maintenance activities at night, is this information communicated to the public?

☐ Yes ☐ No Explain if necessary:

8. Are there any other communication issues that you would like to discuss? ☐ Yes ☐ No Comments:

Risk

Risks in construction work zones are numerous. These risks include vehicle intrusions into work zone or work intruding into vehicle travel ways, workers struck by construction equipment, and construction equipment intrusion in operational traffic lanes.

1. What are the risks (safety, quality, costs, etc.) that you consider in nighttime work?
    a. How different are these risks in nighttime work compared to daytime work?
2. Does your agency use any risk identification techniques (i.e. documents)?

Daytime	Nighttime

3. What are the projects specific documents does your agency use for risk identification?

Daytime	Nighttime

4. What risk management techniques/assessments does your agency use?

Daytime	Nighttime

5. Does your agency use any risk mitigation methods?

Daytime	Nighttime

6. Do you have any innovative ways of mitigating risk/risk analysis? Please explain what they are.

Daytime	Nighttime

7. If maintenance activities are conducted at night, are risks considered? ☐ Yes ☐ No Explain if necessary:

8. Are there any other risk issues that you would like to discuss? ☐ Yes ☐ No Comments:

Cost

In a number of studies the cost of construction has been shown to be impacted by scheduling nighttime construction operations.

1. Has your agency documented cost differences between daytime and nighttime work?

2. How does nighttime work impact construction cost?

3. What are the activities that have greater cost during nighttime work?

    a. Why the change in cost for these activities?

4. Does nighttime work impact the following?

Design cost	**Design effort (i.e., more time required to design work done at night)**	**Design plans/specifications**
☐ Yes How? ☐ No	☐ Yes How? ☐ No	☐ Yes How? ☐ No

5. Does nighttime work impact your agency construction administration cost?

6. Does nighttime work impact road user cost?

☐ Yes How? ☐ No

7. Do you have any innovative ways of minimizing cost for nighttime construction?

   ☐ Yes ☐ No Explain if necessary:

8. If maintenance activities are conducted at night, how is the cost of these activities impacted?

9. Do you have any other cost related issues you would like to discuss? ☐ Yes ☐ No Comments:

Quality

1. Does nighttime work significantly impact construction quality?

2. How frequently does your agency perform formal inspections on nighttime projects?

   a. Is this the same as for daytime activities? ☐ Yes ☐ No Explain if necessary:

3. What is the process involved in conducting formal inspections for nighttime work products?

   a. Is this the same as for daytime activities? ☐ Yes ☐ No Explain if necessary:

4. What are some of the approaches besides inspection does your agency use to ensure that quality is achieved on nighttime projects?

5. Is the quality expected in nighttime projects usually less than daytime projects?

   ☐ Yes ☐ No Explain if necessary:

6. Do you think resurfacing activities at night impact quality?

   ☐ Yes ☐ No Explain if necessary:

7. Do you think asphalt paving activities at night impact quality?

☐ Yes ☐ No Explain if necessary:

8. Do you think concrete paving activities at night impact quality?

☐ Yes ☐ No Explain if necessary:

9. Do you think concrete patching activities at night impact quality?

☐ Yes ☐ No Explain if necessary:

10. Do you think maintenance activities at night impact quality?

☐ Yes ☐ No Explain if necessary:

11. Do you think earthwork activities at night impact quality?

☐ Yes ☐ No Explain if necessary:

12. Do you think striping activities at night impact quality?

☐ Yes ☐ No Explain if necessary:

13. Do you think bridge painting activities at night impact quality?

☐ Yes ☐ No Explain if necessary:

14. Do you think bridge beam installation activities at night impact quality?

☐ Yes ☐ No Explain if necessary:

15. Do you think bridge deck placement activities at night impact quality?

☐ Yes ☐ No Explain if necessary:

16. Do you think bridge substructure activities at night impact quality?

☐ Yes ☐ No Explain if necessary:

17. Do you think bridge substructure repair activities at night impact quality?

☐ Yes ☐ No Explain if necessary:

18. Do you think bridge joint replacement activities at night impact quality?

☐ Yes ☐ No Explain if necessary:

19. Do you think retaining wall work activities at night impact quality?

☐ Yes ☐ No Explain if necessary:

20. Do you have any other quality related issues you would like to discuss? ☐ Yes ☐ No Comments:

Productivity

Productivity is an efficiency measure that is a ratio of output of a product per labor-hour input (i.e. rate of progress or quantities installed per day). There is an intuitive correlation between nighttime work/shifts and losses in productivity.

1. Does your agency keep records of any type of productivity measurement?
   ☐ Yes ☐ No Explain if necessary:

2. Do your contractors keep records of any type of productivity measurements?
   ☐ Yes ☐ No Explain if necessary:

3. Does your agency conduct onsite productivity measurements?
   ☐ Yes (go to 3a) ☐ No Explain if necessary:
   a. How often is onsite productivity measured during daytime activities?
      ☐ Hourly ☐ Daily ☐ Weekly ☐ Monthly ☐ Never ☐ Other Explain if necessary:

4. Does your agency conduct onsite productivity measurements for nighttime activities?
   ☐ Yes (go to 4a) ☐ No Explain if necessary:
   a. How often is onsite productivity measured during nighttime activities?
      ☐ Hourly ☐ Daily ☐ Weekly ☐ Monthly ☐ Never ☐ Other Explain if necessary:

5. How does your agency measure construction productivity?

Method	**Daytime**	**Nighttime**
Contractor reports		
Agency personnel reports		
Photography		
Time-lapse videography		
Activity Sampling		
Random inspection		
Other (please explain):		

6. For the following activities, what is the approximate percent increase/decrease in productivity when they are performed at night? (If not difference is observed use 0%)

Type of Activities	**Productivity Increase/Decrease (%)**
Asphalt Paving	
Concrete Paving	
Concrete Patching	
Bridge Pier	
Bridge Deck Placement	
Bridge Painting	
Bridge beam installation	
Bridge Substructure repair	
Bridge joint replacement	
Pavement Marking	
Pavement Removal	
Grading	
Earthmoving	
Shoulder Work	
Staging and Mobilization	
Other (please explain):	

7. Please rank the following types of activities in order of their impact on nighttime construction productivity (1=highest impact). Are these factors favorable or not to increasing productivity of nighttime construction activities.

Type of Activities	**Rank/Favorable**	**Rank/Not favorable**
Availability of labor		
Worker Fatigue		
Weather Conditions		
Traffic Flow		
Visibility and lighting		
Materials delivery		
Inspections and approvals		
Other (please explain):		

8. If maintenance activities are conducted at night, is productivity impacted? ☐ Yes ☐ No Explain if necessary:

9. Do you have any other productivity related issues you would like to discuss? ☐ Yes ☐ No Explain if necessary:

Nuisances

Nighttime work requirements have caused an increase in disturbances to adjacent property owners. We are seeking examples of best practices in mitigation of nighttime construction nuisances.

Considering your agency's experienced, in order of importance what are the three primary nuisance generators in terms of (1=highest):

Noise: 1. ____________

2. ____________

3. ____________

Vibration: 1. ____________

2. ____________

3. ____________

Lighting: 1. ____________

2. ____________

3. ____________

Dust: 1. ____________

2. ____________

3. ____________

1. Does your agency have specific mitigation techniques to deal with:

Construction Noise: ☐ Yes ☐ No If yes, what are they or can you provide contact information for an individual we could contact for more information.

Construction caused Vibrations: ☐ Yes ☐ No If yes, what are they or can you provide contact information for an individual we could contact for more information.

Construction caused Lighting: ☐ Yes ☐ No If yes, what are they or can you provide contact information for an individual we could contact for more information.

Construction caused Dust: ☐ Yes ☐ No If yes, what are they or can you provide contact information for an individual we could contact for more information.

2. **Community relations** is the key to the mitigation of nighttime construction nuisance problems.

   Has your agency used any innovative community relations programs that should be described in our report? If yes can you provide contact information for an individual we could contact for more information. Are there web links where we could gather additional information? Can you provide copies of any reports describing your efforts?

3. **Source control** is the most effective method of eliminating nighttime construction nuisances.

   Has your agency used any innovative source control methods that should be described in our report? If yes can you provide contact information for an individual we could contact for more information. Are there web links where we could gather additional information? Can you provide copies of any reports describing your efforts?

4. **Path control** of nuisances should be implemented when source controls prove insufficient in adequately minimizing impacts on abutting sensitive receptors.

   Has your agency used any innovative path control methods that should be described in our report? If yes can you provide contact information for an individual we could contact for more information. Are there web links where we could gather additional information? Can you provide copies of any reports describing your efforts?

5. **Receptor control** of a nuisance must be undertaken when all other approaches to mitigation have failed.

   Has your agency used any innovative receptor control methods that should be described in our report? If yes can you provide contact information for an individual we could contact for more information. Are there web links where we could gather additional information? Can you provide copies of any reports describing your efforts?

6. When your agency has a project that will require nighttime work do the contract documents have special provisions to deal with control of nuisances, not already discussed? If so can you provide copies?

7. Many nighttime construction nuisances can be minimized by being carefully considered during design. To minimize pile driving nuisances the Florida DOT has eliminated test piles on some projects and set pile lengths conservatively based on available data. Do you have examples of similar practices you can share with us?

8. If maintenance activities are conducted at night, are nuisance control measures taken? ☐ Yes ☐ No Comments:

9. Do you have any other nuisance related issues you would like to discuss? ☐ Yes ☐ No Comments:

Illumination

Vision, visibility, and light pollution problems are regularly encountered during nighttime construction work. Nighttime construction activities require the creation of adequate lighting conditions.

1. Are lighting plans required prior to placing lights?

☐ Yes ☐ No Explain if necessary:

a. Who provides this lighting plan?

☐ Owner ☐ Contractor Explain if necessary:

b. Who approves the lighting plan?
c. Can field changes be made to the plan?
d. How are field changes made (i.e., drive through, measurements, etc.)?

2. How does your agency inspect lighting conditions in nighttime?

Method	**Yes**	**No**
Illuminance meters	☐	☐
Luminance meters	☐	☐
Photography	☐	☐
Work zone drive-through	☐	☐
Other (please explain):	☐	☐

3. Does your agency keep records of lighting inspections of work zones?

☐ Yes ☐ No Explain if necessary:

4. What is the most important criterion for evaluating lighting conditions on work zones? (Please rank the following criteria; with 1 being best)

Method	**Rank**
Illuminance	
Luminance	
Uniformity	
Glare	
Light trespass	
Other (please explain):	

5. If lighting conditions are inspected in nighttime work zones, how often?

☐ Hourly ☐ Daily ☐ Weekly ☐ Monthly ☐ Never ☐ Other Explain if necessary:

a. Who conducts these inspections?

6. Do nighttime lighting conditions impact any of the following activities?

Type of Activities	**Yes/How?**	**No/Why not?**
Asphalt Paving	☐	☐
Concrete Paving	☐	☐
Concrete Patching	☐	☐
Bridge Pier	☐	☐
Bridge Deck Placement	☐	☐
Bridge Painting	☐	☐
Bridge beam installation	☐	☐
Bridge Substructure repair	☐	☐
Bridge joint replacement	☐	☐
Pavement Marking	☐	☐
Pavement Removal	☐	☐
Grading	☐	☐
Earthmoving	☐	☐
Shoulder Work	☐	☐
Staging and Mobilization	☐	☐
Other (please explain):	☐	☐

7. Please rank the following equipment for their adequacy in providing adequate lighting conditions for nighttime work zones (1=high);

Type of Illumination	**Rank**
Mobile Light Towers	
Stationary Balloon Lighting	
Equipment Mounted Balloon Lighting	
Equipment Lighting (Headlights)	
Portable Lighting Equipment	
Other (please explain):	

b. Do the ranks above depend on activity? Please explain:

c. What drives the use of each type of illumination?

Type of Illumination	**Driving Factor**
Mobile Light Towers	
Stationary Balloon Lighting	
Equipment Mounted Balloon Lighting	
Equipment Lighting (Headlights)	
Portable Lighting Equipment	
Other (please explain):	

8. Do you have any other illumination related issues you would like to discuss? ☐ Yes ☐ No Comments: